DESIGN AND ANALYSIS OF MICROSTRIP ANTENNAS FOR ULTRA-WIDE BAND APPLICATIONS

A Thesis submitted in partial fulfillment of the Requirements for the degree of

Master of Technology

In

Communication and Networks

by

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Rourkela, Odisha, 769008

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Under the Guidance of

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DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

ROURKELA- 769008, ODISHA, INDIA

CERTIFICATE

This is to certify that the work in this thesis entitled "**DESIGN AND ANALYSIS OF MICROSTRIP ANTENNA FOR ULTRA-WIDE BAND APPLICATIONS"** by Mr. **DHUNISH KUMAR** is a record of an original research work carried out by his during 2013-2014 under my supervision and guidance in partial fulfilment of the requirement for the award of the degree of Master of Technology in Electronics and Communication Engineering (Communication and Networks), National Institute of Technology, Rourkela. Neither this thesis nor any part of it, to the best of my knowledge, has been submitted for any degree or diploma elsewhere.

Place: NIT Rourkela

Date: 27th May 2014

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Declaration

I certify that

a) The work comprised in the thesis is original and is done by myself under the supervision of my supervisor.

b) The work has not been submitted to any other institute for any degree or diploma.

c) I have followed the guidelines provided by the Institute in writing the thesis.

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Dhunish Kumar

212EC5165

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Dhunish Kumar

Abstract

The goal of this thesis is to design and analysis the Microstrip Patch Antenna which covers the Ultra Wide Band 3.1 to 10.6 GHz. This thesis covers study of basics and fundamentals of microstrip patch antenna. A series of parametric study were done to find that how the characteristics of the antenna depends on its various geometrical and other parameters. The various geometrical parameters of the antenna are the dimensions of the patch and ground planes and the separation between them and it also includes the dielectric constant of the substrate material. The parametric study also contains the study of different techniques for optimizing the different parameters of antenna to get the optimum results and performance. This is a simulation based study. The design and simulation of the antenna is carried out using CST microwave Studio simulation software. Four antennas with different types of shapes were designed which cover the entire UWB range. The First designed antenna has two half circular patches which are overlapped to each other. A narrow rectangular slit is added to the patch to improve the performance of antenna. The return loss curve shows that the antenna has bandwidth from 3GHz to 12GHz with a minimum S_{11} -45 dB at 3.5 GHz. The second design is elliptical patch antenna with modified ground plane which covers 2.46 Ghz to 13.62 Ghz frequency range has a minimum return loss at resonance frequency 10GHz -50dB. The third and fourth designs are Extended Circular Planar Antenna and Candy Bar Shape Microstrip Patch Antenna that uses defected ground plane and modified ground planes respectively which covers the entire UWB. Return loss curve, antenna gains and the Farfield results are shown for all the designed antennas. Various results reflect the good antenna performance in the UWB range of frequency. Then the effects of varying the parameters of the antenna on its performance are investigated and shown.

In now a days it is essential for an antenna designed for a system to avoid the interference from the other existing wireless system. The antenna should possess a band reject characteristic at interfering frequency bands. Then three compact UWB antenna designs with different notches for the various applications like WLAN, WIMAX, downlink X-band satellite communication and INSAT/Super Extended C-band are proposed.

The first band notch antenna covers the UWB with three band notches for WLAN, downlink X-band satellite communication and INSAT/Super Extended C-band. Second design has the band notches for WIMAX and WLAN application and a band notch characteristic for WIMAX is proposed in third design. Return loss curve, Farfield, antenna gain and surface current distribution in shown which shows that how the band rejection is achieved by creating various defects and slots. Effect of parameter modification are observed and plotted. All the design antennas are fabricated on an inexpensive dielectric substrate FR-4 with relative permittivity (εr) of 4.4 with thickness of 1.6 mm. The simulation results of band notch antennas indicate that the proposed antenna fulfils the excellent band notch characteristics for various frequency bands and showing the good return loss and radiation patters in the interested UWB.

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Chapter 1

Introduction

1.1) Introduction

In now day's the wireless system has become a part of human life. Most of the electrical and electronics equipment around are using the wireless system. An antenna is an essential element of the wireless system. Antenna is an electrical device which transmits the electromagnetic waves into the space by converting the electric power given at the input into the radio waves and at the receiver side the antenna intercepts these radio waves and converts them back into the electrical power. There are so many systems that uses antenna such as remote controlled television, cellular phones, satellite communications, spacecraft, radars, wireless phones and wireless computer networks. Day by day new wireless devices are introducing which increasing1 demands of compact antennas. Increase in the satellite communication and use of antennas in the aircraft and spacecraft has also increased the demands a low profile antenna that can provide a reliable communication.

A microstrip antenna is one who offers low profile and light weight. It is a wide beam narrowband antenna can be manufactured easily by the printed circuit technology such as a metallic layers in a particular shape is bonded on a dielectric substrate which forms a radiating element and another continuous metallic layer on the other side of substrate as ground plane. not only the basic shapes any continuous shape can be used as the radiating patch. Instead of using dielectric substrate Some of the microstrip antennas use dielectric spacers which results in wider bandwidth but in the cost of less ruggedness. Microstrip antennas are low profile antenna and mechanical rugged and can be easily mounted on any planar and nonplanar surfaces. The size of microstrip antenna is related to the wavelength of operation generally $\lambda/2$. The applications of microstrip antennas are above the microwave frequency because below these frequency the use of microstrip antenna doesn't make a sense because of the size of antenna. At frequencies lower than microwave, microstrip patches don't make sense because of the sizes required. Now a day's microstrip antenna is used in commercial sectors due to its inexpensiveness and easy to manufacture benefit by advanced printed circuit technology. Due to the development and ongoing research in the area of microstrip antenna it is expected that in future after some time most of the conventional antenna will be replaced by microstrip antenna.

1.2 Objective of the Work

The common shapes of the microstrip patch are rectangular, square, circular, triangular, etc. All these have been theoretically studied and there are well established design formulae for each of them. Antenna design is an innovative task where new types of antenna are studied. So, here a new shape of microstrip patch antenna is designed which will cover the entire Ultra Wide Band. One of the major problem for UWB systems are electromagnetic interference (EMI) from existing frequency bands, because there are many other wireless narrowband application that are allocated for different frequencies band in the UWB band.

Therefore it is necessary for the designer to design the UWB antenna they can reflect the interference from the other existing bands. To overcome this interference problem UWB antennas should have band notches therefore they can reject the existing frequency bands within the ultra-wide band. Here three designs with different band notches for UWB applications are proposed.

The goal of this thesis is to study how the performance of the antenna depends on various parameters of microstrip patch antenna. This is a simulation based study. CST Microwave studio software, one commercial 3-D full-wave electromagnetic simulation software tool is used for the design and simulation of the antenna. Then, the antenna parameters are varied to study the effect of variation of the antenna parameters on the antenna performance.

1.3 Outline of the Thesis

Chapter 1 of the thesis contains the overall introduction to the microstrip antenna and this chapter also concluded with the details of outline of the present thesis.

Chapter 2: this chapter is dedicated to Literature Survey of my thesis gives an overview about the microstrip antenna; the mechanism of radiation behind the microstrip antenna, advantages and disadvantages as compare to their counterpart and finally the major applications in different fields. All the popular feeding methods used in microstrip antenna with their significance are also discussed in this chapter.

Chapter 3: The basic parameters on which the selection and performance of an antenna is characterize, are Bandwidth, Antenna Polarization, radiation, Pattern, Efficiency, Antenna Gain are described in brief in this chapter.

Chapter 4: In this Chapter two basic and mostly used microstrip patch Rectangular and Circular patch is discussed this chapter also deals that how the design parameters are calculated and their effect on the antenna performance.

Chapter 5: This chapter deals with the design and simulation of four microstrip patch antenna of different shapes. Various methods for increasing the bandwidth are also applied. Various simulation results and graphs characterizing the antenna performance are plotted and the effect of various antenna parameters on the antenna performance is also observed and compared and shown in the chapter. This proposed antenna structures are simulated in CAD software Microwave Studio in Computer Simulation Technology Simulator (CST), one commercial 3-D full-wave electromagnetic simulation software.

Chapter 6: In this chapter the requirement of Band Notch Antenna in UWB is discussed. It contains the design and simulation of three different microstrip patch antenna. Various techniques for getting the band notch is implemented in the designs. Effects of modification of antenna parameters on the various results and graphs of the antenna are also studied and plotted.

Chapter 7: Contains the conclusion of the thesis and future work.

Chapter 2

Fundamentals of Antenna

Different types of application requires antenna with different parameters. Like for cellular mobile communication a circular polarized antenna is requires with high gain and for satellite communication in downlink a high directive antenna is required. The selection and the performance of an antenna is characterize on the basis of some parameters these are Bandwidth, Polarization, radiation, Pattern, Efficiency, Gain. These parameters are described in brief below

2.1) Radiation Patterns:

Also known as Antenna Pattern or Far-Field Pattern. Radiation pattern of an antenna is graphical representation of radiated power at as fix distance from the antenna as a function of azimuth and elevation angle. So the antenna pattern shows that how the power is distributed in the space. For simplicity the radiation pattern can be drawn in 2D plane for different azimuth and elevation angle referred as azimuth plane pattern and elevation plane pattern. It is good to plot the radiation patterns in Cartesian (rectangular) coordinates, especially when antenna radiation pattern consists of different side lobes and where these side lobes levels plays an important role. There are different types of antenna patterns described below

a. Omnidirectional Antennas:

Omnidirectional antenna can be referred as an antenna has radiation pattern uniform and equally distributed in one plane generally referred to horizontal planes. Some applications like mobile, cell phones, FM radios, walkie talkies, wireless computer networks, cordless phones, GPS, many portable handheld devices and in base stations antenna required with the characteristics that can radiate equally in a plane. Omnidirectional antenna has radiation pattern like doughnut shaped. Slot antenna and dipole antenna, whip antenna, discone antenna, duck antenna are some good example of low gain omnidirectional antenna. Omnidirectional antenna with high gain can also be design by narrowing the beamwidth of the antenna in the vertical plane will result in concentrating of energy in horizontal plane. Therefore a narrow beamwidth antenna has a high gain and different type of omnidirectional antenna with various gains can be design. A 0dBd gain antenna radiates more efficiently in vertical plane.

b. Directional Antennas:

As the name suggest directional antennas concentrate their radiation in a particular direction. They are also known as Beam Antenna. They are useful in some point to point application like satellite communication, in base station antenna to transmitting energy in a particular sector. Yagi, horn, log-periodic antenna and panel antenna are some example that have directional radiation pattern.

c. Isotropic radiator:

An Isotropic antenna has the radiations distributed uniformly in all direction. An isotropic antenna radiates all the power given. It is an imaginary antenna does not exist practically. It is used as a reference to compared with the other antennas.

2.2) <u>Field Regions:</u>

The radiations from antennas are varies when we go apart from the antenna. The field regions can be categorized in Far field region and Near Field (Fresnel) Region. Far field region is the region beyond the Fraunhofer distance called Fraunhofer region. It is the region after that the radiation patter does not change with the distance. The Fraunhofer distance is related to antenna's larger dimension and can be calculated as:

$$R = \frac{2D^2}{\lambda}$$

Where

R= distance from antenna

D= larger dimension of antenna

λ= wavelength in free space

2.3) Directivity:

Directivity of an antenna shows that how much the antenna is able to radiate in a particular given direction. It is a major requirement when antenna is working as a receiver. If an antenna radiates equally in all direction then then the directivity of antenna is 1 or when measured with respect to isotropic antenna is 0dB. Directivity in its simple form can be described as the comparison of maximum radiation intensity to average radiation intensity. As

$$\text{Directivity} = \frac{\text{maximum radiation intensity}}{\text{average radiation intensity}}$$

Directivity of an antenna with given angle shows that the antenna radiations are more concentrated in that given direction when talking about antenna at transmitting end. While in case of receiving antenna it will receive the power efficiently from the particular direction.

2.4) Gain:

Antenna Gain is also referred as Power gain or simply Gain. This combines of antenna efficiency and directivity. For a transmitting antenna it shows how efficiently antenna is able to radiate the given power into space in a particular direction. While in case of receiving antenna it shows how well the antenna is to convert the received electromagnetic waves into electrical power. When it is calculated with efficiency $E_{antenna}$ and directivity D it is referred as Power Gain.

$$\text{Power Gain} = E_{antenna} \,.\, D$$

When the directivity with a particular direction is given it is known as Directive Gain.

$$\text{Directive Gain } (\theta,\pi) = E_{antenna} \,.\, D\,(\theta,\pi)$$

2.5) Antenna polarization:

Polarization of an antenna is polarization of the electromagnetic waves radiated from the antenna. Polarization on a wave is the orientation or path traces by the electric field vector as a function of time. Polarization can be categorized in three parts

a. Linear polarization
b. Circular polarization
c. Elliptical polarization.

If the electric field vector of the wave at a given point in space follows a linear path then the polarization is linear. Linear polarization is of two types Vertical and Horizontal. In case of circular and elliptical polarization electric field vector follows a circular and elliptical path. They can be Left hand polarized, if the electric field vector tracking the path by making clockwise rotation and Right hand polarized, if the vector tracking the path by making anti clockwise rotation.

2.6) Antenna Bandwidth:

Antenna bandwidth is another important parameter of antenna can be described as the range of frequencies over which antenna fulfil some desired characteristics. Bandwidth can be described on the basis of gain, axial ratio bandwidth, Impedance or vswr bandwidth. The impedance bandwidth is the range of frequencies over which the input impedance of antenna is perfectly matched to the characteristic impedance of the feeding transmission line. Impedance bandwidth related to Q factor can be described as

$$\mathrm{BW} = \frac{s-1}{Q_T\sqrt{S}} \qquad \text{(VSWR S: 1)}$$

Generally Fractional bandwidth is used for microstrip antenna. Given by

$$BW = \frac{f_h - f_l}{fc}$$

Where f_h and f_l are the upper and lower frequencies where the VSWR matches to S: 1. Generally VSWR is taken 2:1 and ideally it is 1:1. To maximize the impedance bandwidth for VSWR 2:1 proper impedance matching is required. That is we have to feed at the driving point where antenna impedance is Z_0 = 50 ohm generally. One can get a little bit more bandwidth by feeding at the point where the antenna impedance is 65ohm.

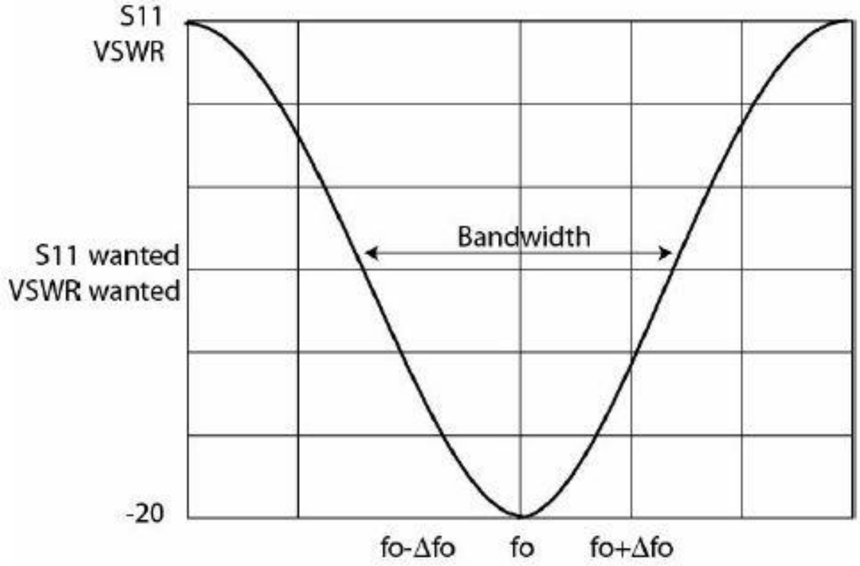

Figure 2. 1Bandwidth

Chapter 3

Theory of Microstrip Patch Antenna

3.1 History

Earlier in the 19th century in microwave circuitry we have started using coaxial cable and twin parallel wire line as the transmission lines. In the mid-20^{th} century the invention of printed circuit board technology allow us to make the printed circuit versions of these transmission lines which were very inexpensive and simple. The two wire transmission line in printed circuit version is known as microstrip line, has a metallic ground plane providing the virtual 2nd conductor and the coaxial line cable is adapted in printed circuit version as Stripline. The attention on the fact that these microstrip structures can be used as radiator for electromagnetics wave got in 1950s. First in year the 1953 Deschamps introduces the concept of microstrip radiators[1]. In 1955 a patent on the name of Gutton and Baissinot was issued in France [2, 3]. After getting the concept of microstrip radiator about 20 year a practical microstrip antenna was fabricated. Earlier these microstrip radiators were limited in the laboratories no commercial antennas are available at that time due to high loss and poor radiation. One of the reasons was unavailability of good dielectric material with minimum loss tangent which can use as substrate and can radiate efficiently. At that time stripline got more attention due to easy to design, analysis and suitable to microwave planar structure and it also allows transverse electromagnetic wave (TEM) [3]. In 1955 R. M. Barret commented that “advantages of stripline and microstrip line are essentially the advantage of coaxial and twin wire transmission line”[5]. May be these were some reasons microstrip radiators didn’t get the instant attention in that period.

The research on microstrip radiator got attention when some good dielectric material were found with better thermal and mechanical properties has a low loss tangent. In 1969 Denlinger found the microstrip radiators with rectangular and circular shape could be able to radiate efficiently [6].

Researchers had found previously that the half of the input power would escape in microstrip radiator as a radiation. Denlinger found the mechanism behind the radiation that if microstrip line is left open ended at the end this discontinuity will cause the electromagnetic waves to arise from the each open end. It was realized that the radiations will be more from the discontinuity when these are separated by half of wavelength distance or a multiple of that long to each other. It was also realized that the amount of power radiated from the open ends will increase if the height of the dielectric substrate increases. Denlinger noted that by increasing the height of substrate microstrip radiators was able to radiate the 70% of power available. He also carried his research on circular microstrip radiators and found that it was possible to attain up to 75% of radiation from a circular microstrip radiators. Microstrip radiators were now termed as microstrip antenna. One of the major benefit of microstrip antenna is that they are very comfy to planar and nonplanar surfaces can be easily mounted on that. This was the main reason that the microstrip antenna acquired the serious attention to the researchers in early 1970s when high performance application such as aircraft, spacecraft, missile, satellite communication put the motivation for researchers to investigate on usefulness of conformal microstrip antennas. After about 2 years Howell introduced a basic rectangular shape microstrip antenna that was fed using the microstrip transmission line. In that days microstrip antenna was a major focus for investigators. Researchers introduced many various designs. But it was difficult to get the better radiation efficiency that was limited upto 90%. Narrow bandwidth was also a severe problem for microstrip antenna. By 1981 research and study of microstrip antenna got a drift when IEEE made the microstrip antenna a special issue in the *IEEE Transaction on Antenna and propagation*[7].

3.2 Microstrip Antenna

In a most basic form a microstrip antenna comprises of two thin metallic layers ($t<<\lambda_0$, where λ_0 is wavelength in free space) one as radiating patch and second as groundplane and a dielectric substrate sandwiched between them. The conductor patch is placed on the dielectric substrate and used as radiating element. On the other side of the substrate there is a conductive layer used as ground plane. Copper and gold is used normally as a metallic layer. Radiating patch can be of any shape but simple shapes are used to design a patch because patches basic shapes are easy to analysis by the available theoretical models and it is easy to predict the performance. Square, rectangular, dipole, triangular, elliptical, circular are some basic shapes. Circular, rectangular and dipole are the most often used shapes because of easy of analysis and fabrication. A variety of dielectric materials are available for the substrate with dielectric constants $2.2 \leq \varepsilon_r \geq 12$[8]. The height of substrate plays an important role in antenna characteristics generally are in the range $0.003\lambda_0 \leq h \geq 0.05\lambda_0$.

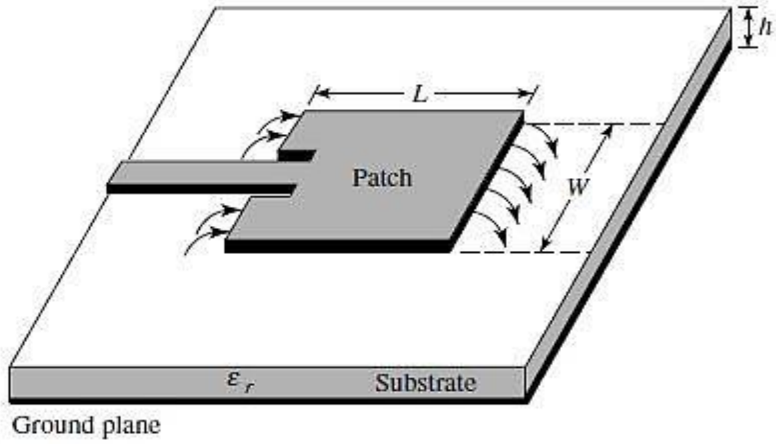

Figure 3. 1 Microstrip Patch Antenna

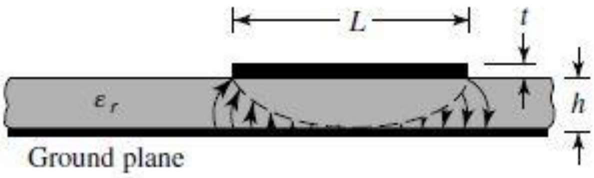

Figure 3. 2 Side view of Microstrip Patch Antenna

Microstrip antenna suffers from very Narrow frequency bandwidth. However some application where narrow bandwidth is essential such as government security systems, microstrip antennas are useful. Bandwidth of microstrip antenna is directly proportional to height of substrate. There are two main techniques two improve the bandwidth; one *circuit theory* and second *structural.*

An antenna characteristics is not only depends on the antenna element but also be influenced by the TX-line and antenna combination. Generally the input impedance of microstrip antenna is complex and the characteristic impedance of TX-line is real (usually 50 ohm). This will results in impedance mismatching and causes a voltage standing wave pattern on transmission line results in low impedance bandwidth. One way to overcome this problem is use of impedance matching networks between antenna and transmission line. There are several impedance matching techniques are available, Circuit theory deals with the impedance matching techniques.

Structural technique deals with the modification of substrate properties such as height and dielectric constant. By increasing the height we can increase the bandwidth. But it will also introduce surface waves which increases loss of the power and leads to performance and characteristics degradation. Various types of methods are introduced by the researchers such as stacking, defected ground plane, parasitic patches and improvement of bandwidth of microstrip antenna is still an interesting topic for investigation. By choosing a particular shape one can easily design an antenna with desired resonance frequency radiation pattern, polarization. It is easy to design a microstrip antenna with reconfigurable polarization, resonance frequency and radiation patterns just by adding loads like PIN diode, Varacter diodes.

*3.3 **Radiation mechanism***

In 1969 denlinger noted that if the microstrip line left open ended on one end and fed on the other end then due to the discontinuity created some part of the power is radiated in the space from both the ends as electromagnetic waves. Denlinger also realized that the amount of power radiated in space is maximum when both the discontinuities kept a half wavelength or a multiple of half of wavelength apart from each other[6]. Denlinger concluded that radiations took place from the open end due to the fringing fields arising from the discontinuity. To understanding the mechanism behind the radiation from microstrip antenna considers a rectangular antenna with a half wavelength long radiating patch fed by microstrip feed line. A rectangular antenna can be considered as a microstrip line left open ended on one side and energy is fed from the other end. Since the patch is half wavelength long and left open ended on other side, the current at the corners (at the beginning and end) of the patch should be zero and is maximum at the centre of the patch. Current and voltage will be 90 degree out of phase. The voltage will be maximum positive at the beginning and maximum negative at the end of patch[9].

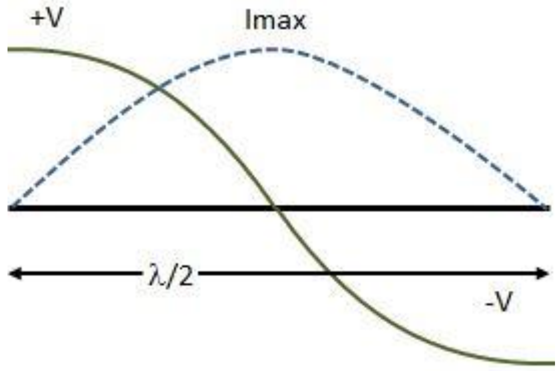

Figure 3. 3 Current and voltage variation along the Patch length

Field distribution along the patch is like shown in figure below. The field lines are below the patch towards corner are opposite in direction. This field lines does not stop abruptly ant the end. At the corners fringing fields are created and the field lines are in bow shape. More the fringing field bow more the radiation. Therefore these fringing are the reason behind the radiation from the microstrip antenna.

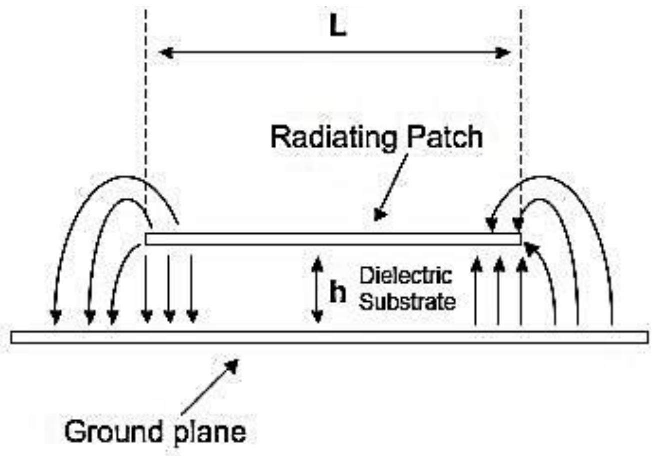

Figure 3. 4 Fringing fields

3.4 Advantages and Disadvantages:

Microstrip antenna is a low profile antenna that has light weight and is very easy to installation due to which it is very popular in handheld wireless devices such as cell phones, pagers and in some high performance communication systems such as in satellite, missile, spacecraft, aircraft etc. Some of the major advantages of microstrip antenna as discussed by Randy Bancroft [3] and Garg [10] are given below:

- Inexpensive and easy to fabricate.
- Can be planted easily on any surface.
- Can easily get reconfigurable characteristics.
- Can easily design antenna with desired polarization.
- Mechanically robust, Resistant against vibration and shock.
- Suitable to microwave integrated circuits (MICs).
- For high gain and directivity Array of antennas can be easily formed.

Conversely microstrip antennas also have a number of disadvantages and limitations when compared to other antennas. Some of the major disadvantages of microstrip antennas are written below:

- High quality factor.
- Cross polarization.
- Poor polarization efficiency.
- Suffers from spurious feed radiation.
- Narrow impedance bandwidth (5% to 10% without any technique)
- High Dielectric and conductor losses.
- Sensitive to environment conditions like temperature and humidity.
- Suffers from surface wave when high dielectric constant material is used.
- Low gain and power handling capability.

There are various methods to overcome this limitations, bandwidth of microstrip antenna can be increase by using some special methods like defected ground plane strategy, stacked patches, slotted patches, parasitic patch. Gain and the power handling ability of antenna can be improved by making an antenna array. Use of Electromagnetic Band Gap (EBG) structure and metamaterial also results in the improvement of the antenna characteristics[20].

3.5 Applications

After a number of limitations due to the several advantages microstrip antenna found very useful in different applications. Microstrip antenna widely used in the defence systems like missiles, aircraft, satellites and rockets. Now a day's microstrip antenna is used in commercial sectors due to its inexpensiveness and easy to manufacture benefit by advanced printed circuit technology. Due to the development and ongoing research in the area of microstrip antenna it is expected that in future after some time most of the conventional antenna will be replaced by microstrip antenna. Some of the major applications of microstrip antennas are:

- Mobile Communication:-

Antenna used in mobile applications should be light weight, small size. Microstrip antenna possesses this entire requirement. The most of mobile applications are handheld gadgets or pocket size equipment, cellular phones, UHF pagers and the radar applications in vehicles like car, planes, and ships. Various types of designs are made and used for radar applications like marine radar, radar for surveillance and for remote sensing.

- Satellite Communication :-

In satellite communication antenna should have the circular polarization. One of the major benefit of microstrip antenna is that one can easily design an antenna with require polarization by using dual feed networks and different techniques. Parabolic antennas are used in satellite communication to broadcasting from satellite. A flat microstrip antenna array can be used in the place of parabolic reflector.

- Global Positioning System :-

Initially the satellite based GPS system are used for only in military purposes but now a day's GPS found a large application in everyone's life and now used commercially. GPS found an essential requirement in vehicles, ships and planes to track the exact location and position. 24 satellites are working in GPS encircling the earth in every 12 hours at altitude 20,200 km. GPS satellite using two frequencies in L-band to transmit the signal which is received by thousands of receivers on earth. The receiver antenna should be circularly polarized. An omnidirectional microstrip antenna has wide beam and low gain can be easily design with dual frequency operation in L-band.

- Direct Broadcast Satellite System:-

In many countries direct broadcasting system is used to provide the television services. A high gain (~33db) antenna should be used at the ground by the user side. A parabolic reflector antennas are generally used are bulky requires space and affected by snow and rain. An array of circularly polarized microstrip antenna can be used for direct broadcasting reception. Which are easy to install, has less affect from snow and rain and cheaper also.

- Antenna for Pedestrian:-

For pedestrian applications antenna should be as small as possible due to space constraints. Low profile, light weight and small structure antennas are generally used in the handheld pocket equipment. Microstrip antenna is the best candidate for that. Various types of techniques can be used to reducing the size of antenna like short circuiting the patch or using the high dielectric constant material. But it has a drawback that smaller antenna leads to poorer efficiency.

- In Radar Applications :-

Radar application such as Manpack radar, Marine radar and Secondary surveillance radar requires antenna with appropriate gain and beamwidth. An array of microstrip antenna with desired gain and desired beamwidth can be used. For some application such as sensing the ocean wave speed and direction and for determining the ground soil grades Synthetic Aperture radar method is used. Two arrays of patch antennas separated by a proper distance are used in this system.

- Application in Medical Science:-

In medical science for treating the malignant tumors microwave energy is used to induce hyperthermia. The microwave energy radiator used for this should be adaptable to the surface being treated and should be light weight. Microstrip patch antenna is the only one that can fulfil that requirement. Annular ring and circular disk microstrip antenna are some examples. A half circular flexible patch monopole microstrip applicator used is shown in figure below. Figure shows the geometry of the applicator that how it is conform on the curved surfaces[11].

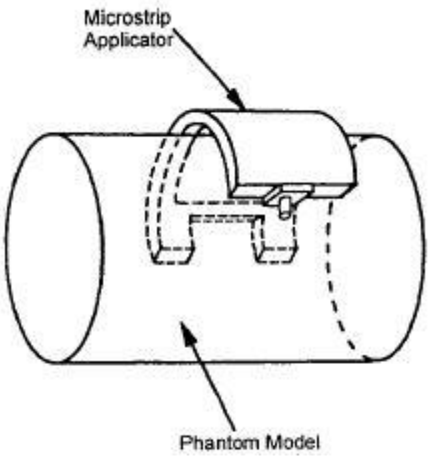

Figure 3. 5 Microstrip applicator used for hyperthermia application

3.6 Feeding Techniques

Various types of feeding techniques are available to feed microstrip antenna. Each of them has their own merits or demerits. A number of factors are used to choose which type of feeding is suitable for the designed antenna. The main consideration is effectual power transfer from feed line to the antenna radiating element that is proper matching between the feed and antenna. Various techniques like impedance transformer, stubs are used for impedance matching. Feed structure should like that these matching structure could be fabricated with radiating element easily. Spurious feed radiation and surface wave losses are also the major factors which depend on the feeding methods which affects the antenna characteristics. Surface waves decreases the efficiency of antenna and spurious feed radiation results in undesired radiation which will give rise to side lobe level and also increases level of cross polarization. Another main feature is that feed network should be well-suited to make an array, feeding methods can be divide in two categories one is contacting feeds and other one is non contacting feeds or electromagnetic coupled feed. In contacting feeds the feed line is directly connected to radiating element. The main drawback of contacting feeds are that it shows inherent asymmetry which produces the higher order modes that leads to increase in cross polarization level. To minimize these noncontacting feeds are used. Microstrip line feed and coaxial probe feeding are two mainly used direct contact feedings and aperture coupled and proximity coupling are two noncontacting couplings which are described in brief below:

3.6.1) Microstrip line feeding:-

In this type of feeding the radiating patch is directly fed by the microstrip feed line has a narrow width as compare to patch. It is the simple and mostly used feeding method. Because microstrip line can be treated as extended part of radiating patch and fabricated on the same substrate on the board. This feeding simple to fabricate and it’s easy to impedance matching techniques are very compatible with this type of feed. But this feed also have some drawbacks, suffers from spurious feed radiation and surface wave losses also has low bandwidth.

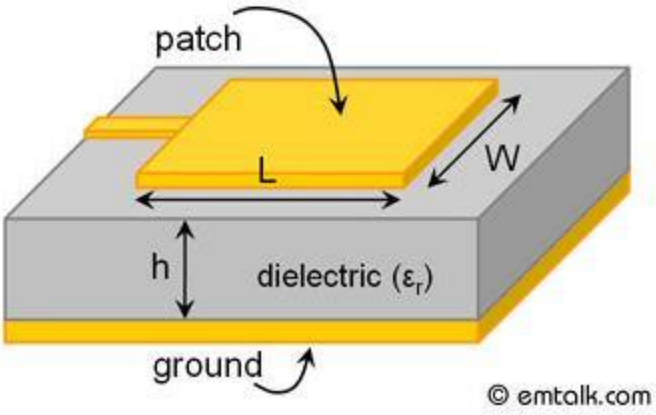

Figure 3. 6 Microstrip Patch Antenna

3.6.2) Coaxial probe feed:-

One of the widely used feeding for microstrip antenna. In this type of feeding core of coaxial cable is directly connected to the patch using the soldering and the outer cable is connected to the ground. Core conductor is inserted in the substrate via a hole. The main advantage of this feeding is that we can directly feed or connect the inner conductor to the feed point where the input impedance is equal to the characteristic impedance of the feed line.

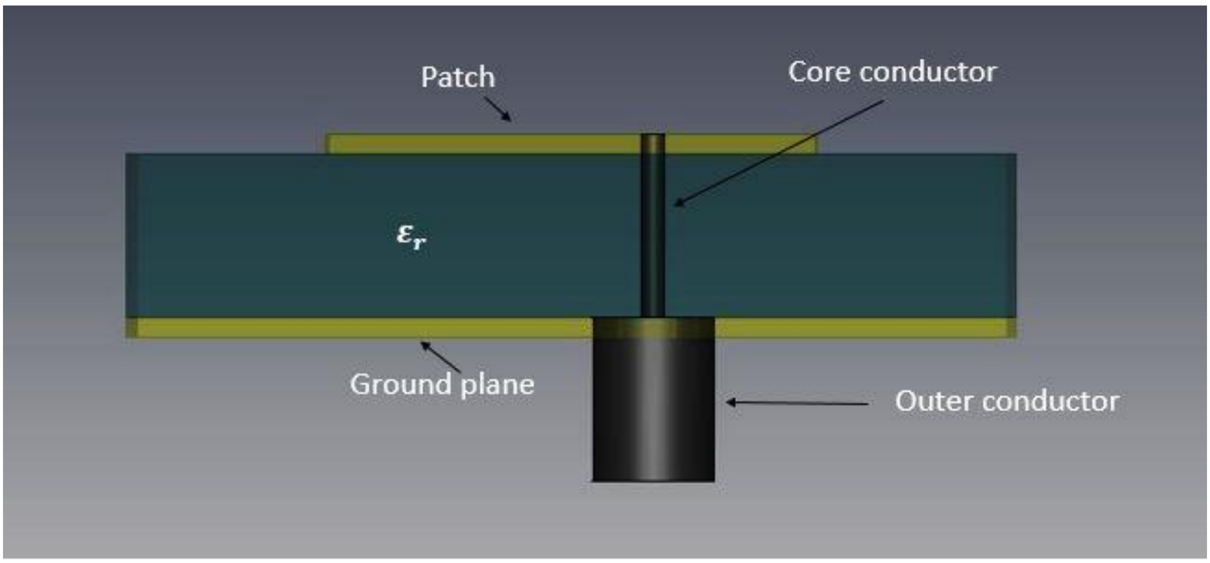

Figure 3. 7 Coaxial Probe Feed

3.6.3) Proximity coupled feed:-

Two types of dielectric substrates are used in this type of feeding. Microstrip line is not directly connected to patch and left open ended and is sandwiched between the substrates. Energy from feed line is coupled electromagnetic to the radiating patch. The microstrip line can be extended as stub to increase the bandwidth. Substrates dielectric constants play a lead role and selected to increase the bandwidth and decrease the spurious feed radiations from the feed line. Thick Material with low dielectric constant is selected for Upper substrates because lower the dielectric constant more the fringing field and more the radiations from patch and thin substrate with high dielectric constant is selected for lower substrate. This type of feeding has largest bandwidth as compared to others. It is easy to model and has low spurious feed radiation however its fabrication is more difficult because the exact alignment of feedline is required. The length of the extended stub and width to line ratio of patch can be optimized to control the antenna characteristics.

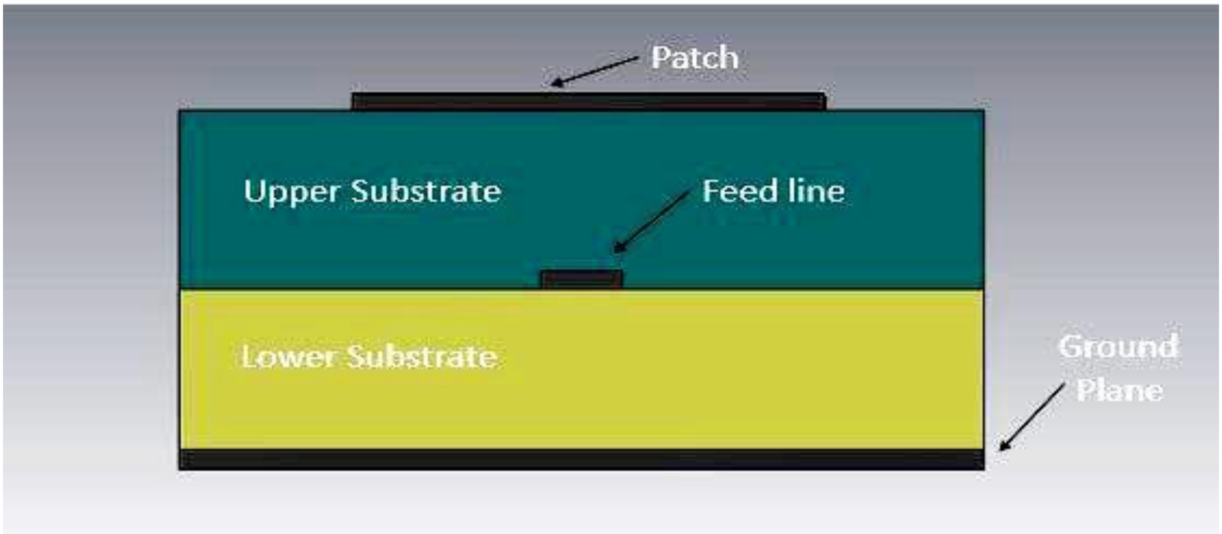

Figure 3. 8 Proximity Coupled Antenna

3.6.4) Aperture coupled feed:-

Structural view of this type of feeding is shown in figure. As shown this feeding also uses two type of substrate ground plane is placed between them and microstrip line is used generally to feed which is placed below the lower substrate. As name suggests in aperture coupling feeding the energy is electromagnetically coupled to the patch through an aperture or slot made in the ground plane. Different types of aperture shapes are used generally rectangular and circular shapes are widely used. Cross shaped and annular ring shape slots are used for exciting the circular polarization. The parameters of slots are used to improve the antenna characteristics. As in proximity coupled feeding substrates dielectric constant is selected to get better radiation and bandwidth. Thick substrate with low dielectric constant is used for the upper substrate to get the good radiation and bandwidth. While thin and high dielectric constant material is used for the upper substrate to for efficient transfer of energy from feedline to patch. To get the maximum coupling between feed structure and the patch slot should be located at the place where the magnetic field is maximum[16]. We know that from the current and voltage distribution along the patch length, electric field is maximum at the ends and magnetic field is maximum at the centre of the patch. The microstrip feed line is extended a length extra and is used as a stub. Stub works as an open circuited transmission line has admittance is in parallel to that of the slot. By optimizing the extended length of feedline (stub) the reactive components of slot can be cancelled out to that of the stub that will result in better impedance matching.

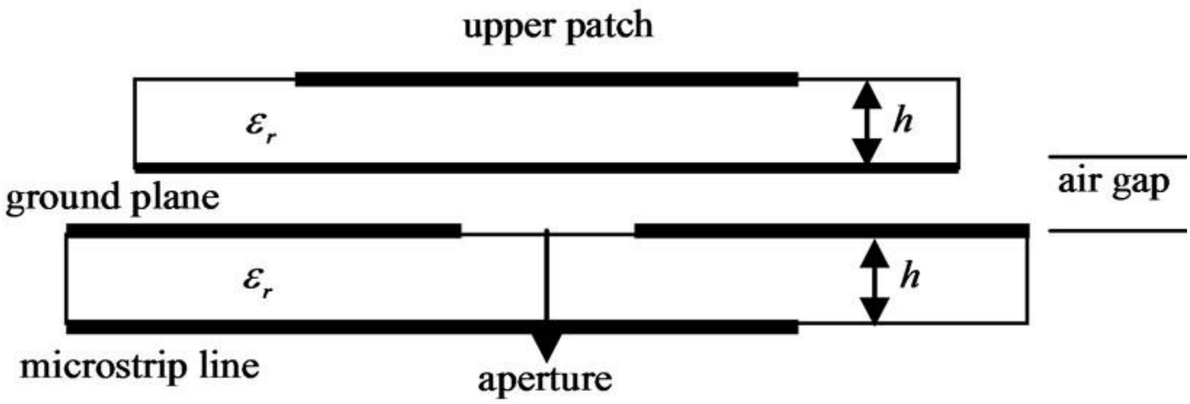

Figure 3. 9 Aperture Coupling

The area of slot is kept small to minimize the radiation below the ground plane. This type of feeding has better polarization purity, low spurious feed radiation and large bandwidth as compared to microstrip and coaxial probe feeding. The equivalent circuit for each of them is shown in figure below.

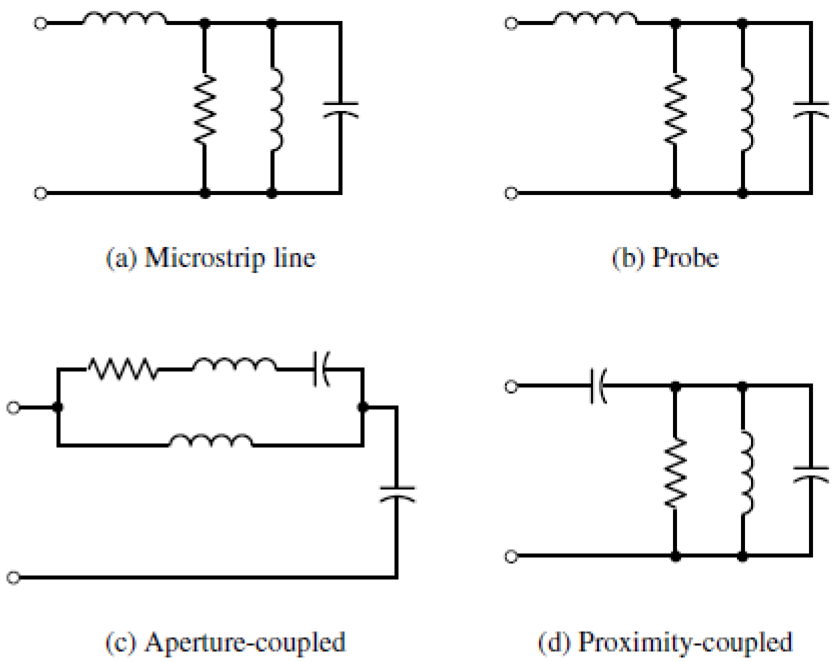

Figure 3. 10 Equivalent Circuit for Feeding Techniques

Chapter 4

Rectangular and Circular Microstrip Antenna

4.1) Rectangular Microstrip Antenna

The rectangular microstrip patch is probably the most common designed antenna. The figure shows a normal rectangular patch antenna. Here a designer has two degree of freedom length and width of patch. The metallic patch is separated from the ground plane by a fraction of wavelength distance above by the dielectric substrate. The field varies over the length are shown. The fringing fields are coming out from the two edges are referred as radiating edges and other two edges as nonradiating edges.

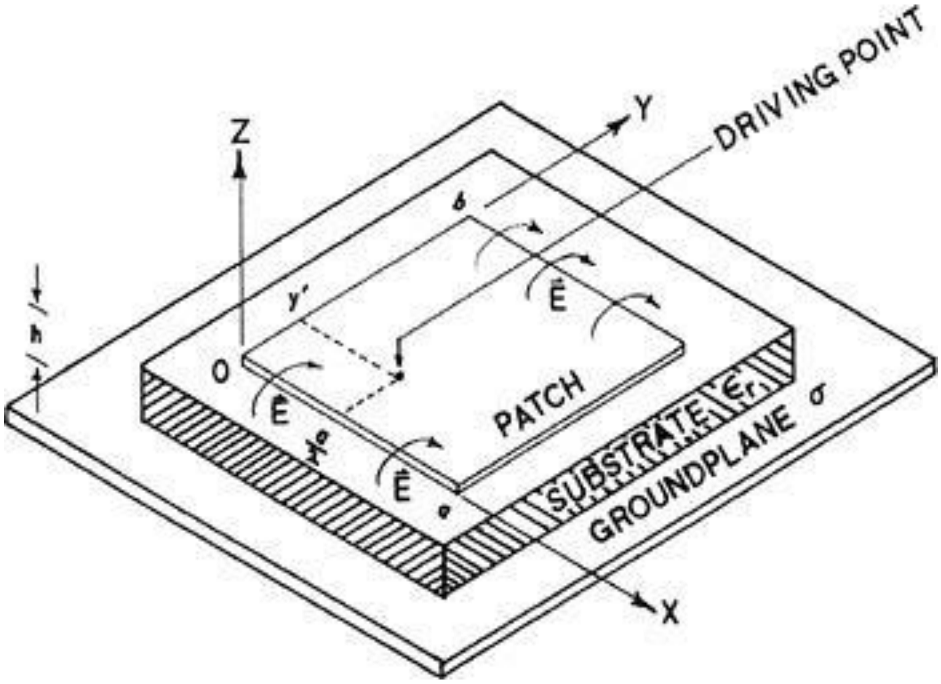

Figure 4. 1Rectangular Patch Antenna

Patch shown in figure has length b and width a. The patch antenna is fed by using coaxial line feed and the feed point is on the middle line on the patch y' distance apart along the length b.

4.1.1) ***<u>Methods of Analysis:</u>***

A number of methods are available for analysing the microstrip antenna. Two mostly used models are named below. Transmission line model is easiest one and provides a simple physical implementation of the antenna but is less accurate, While the Cavity model is difficult but more accurate.

- Transmission Line Model
- Cavity Model

4.1.1a) ***Transmission Line Model:***

The transmission line model treated rectangular microstrip as a part of transmission line. As the rectangular microstrip antenna consists two radiating slots, transmission line model represents each radiating slots by an equivalent admittance which are separated by a distance equal to the length. The resistive part of them represents the radiation loss from the each slots. At the resonance the reactive part of the input impedance cancelled out and the input impedance become pure resistive. Transmission line model consider the effects of various parameters described below.

a. Fringing Field :

The fringing field in rectangular microstrip antenna arises from the radiating edges shown in the figure below. Fringing field are mainly depends on the dielectric constant and length L to height h ratio. Since in most of the cases the L/h ratio is << 1 therefore the fringing fields are less.

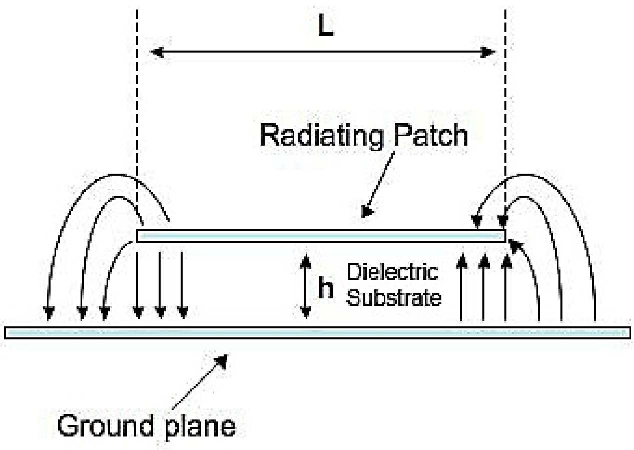

Figure 4. 2 Fringing Field Effect

Higher dielectric constant substrate leads to bounded electric fields more enclosed in the substrate as used in the microstrip lines. While the lower dielectric constants substrates results in loosely bounded electric fields means they will go more further from the patch. Lesser the dielectric constant material used in substrate more bowed the fringing fields. We know that the fringing fields are responsible for the radiations from microstrip antenna. Therefore lower dielectric constant more the fringing fields and more the radiations leads to better efficiency and better antenna performance. From figure it can be seen that fringing fields lines are not only enclosed in substrate but also go further out in the air. As the field lines travels in substrate and air also we have to calculate an Effective Dielectric constant by taking the air also in account.

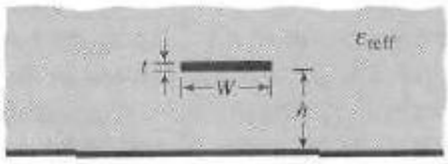

Figure 4. 3 Effective Dielectric Constant

The effective dielectric constant is a dielectric constant of the material for which the antenna characteristics are same as for the real one. The range of effective dielectric constant varies from 1>ε_{reff} <ε_r. In most cases the ε_{reff} value is close to ε_r. If the air is used as a substrate then the effective dielectric constant is equal to dielectric constant ε_{reff} =ε_r. The ε_{reff} is also depends on frequency. As the operating frequency increases the value of effective dielectric constant reaches to the real value of dielectric material used. Graph below showing the variation of effective dielectric constant with the frequency below. For the lower frequency the effective dielectric constant does not varies but as the frequency increases the effective dielectric constant approaches towards the actual dielectric constant of substrate material.

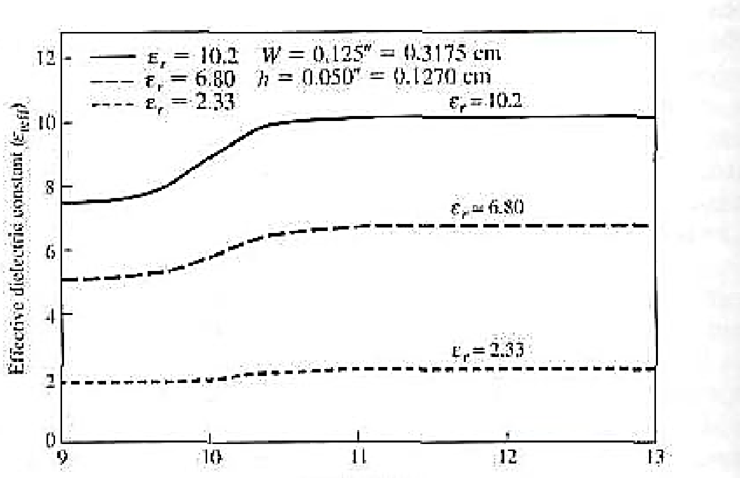

Figure 4. 4 Dielectric Constant Vs Frequency curve

The ε_{reff} for W/h>1 can be given as

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+12\frac{h}{W}\right)^{-1/2}$$

b. Effect of fringing fields on Length:

Due to the fringing field coming out from the radiating slots the actual length of rectangular patch is more than the physical length. Then we have to introduce a length extension factor. This is in the case when mode are generated along the length or linear polarization is made. Length extension should also be consider when fields are generated by radiating edges along width. The best approximated value of this length extension normalized to dielectric material height can be given by formula

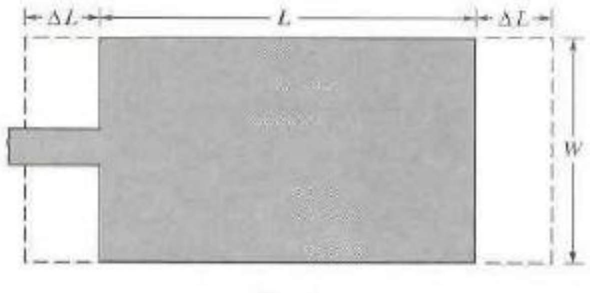

Figure 4. 5 Length Extension

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff}+0.3)(W/h+0.264)}{(\varepsilon_{reff}-0.258)(W/h+0.8)}$$

This ΔL value mainly depends on the effective dielectric constant and the width to height ratio. Due to this length extension length of patch is about 0.48λ rather than 0.5λ. Therefore to get the actual physical length of the patch equal to λ/2 we have consider the extension on both the ends and that is,

$$L = L_{eff} - 2\Delta L$$

As we know for dominant mode TM_{010} the length pf patch is equal to λ/2 therefore the L_{eff} is given by

$$L_{eff} = c/f_r$$

$$= \frac{c_0}{2f_r\sqrt{\varepsilon_{reff}}}$$

Where c_0 is the velocity of light in free space and f_r is the resonance frequency for which antenna is to be design.

c. Patch Width:

For the dominant mode TM_{010} there is no fringing fields along the width therefore there is no need to consider the effective dielectric constant. Width of the patch can be calculated by this formula

$$w = \frac{c_0}{2f_r}(\frac{\varepsilon_r+1}{2})^{-1/2}$$

d. Resonance Frequency

For the dominant mode TM_{010} the antenna resonates (without taking fringing into account) at the frequency given by

$$f_r = \frac{c_0}{2L\sqrt{\varepsilon_{reff}}}$$

And when considering the effective length and effective dielectric constant the antenna will radiate at the frequency

$$f_r = \frac{c_0}{2(L+2\Delta L)\sqrt{\varepsilon_{reff}}}$$

e. Input Impedance:

It is important for the perfect impedance matching to find the point along with the patch dimension where the input impedance is equal to that of that of the feedline referred as Feed point or Driving point. The input impedance at feed point or driving point is known as Driving Point Impedance. The current and voltage distribution over the patch length is shown in figure. Voltage is maximum at the corners and current is maximum at the centre. As we know that the resistance is the ratio of voltage and current. Therefore the resistance will be maximum at the corners and minimum at the centre.

Input impedance of the rectangular patch antenna along the centre line at any point can be determined by the transmission line model. The transmission line model for rectangular patch antenna is shown in figure. Each radiating edge is shown by parallel equivalent admittance y_e and are separated by a distance equal to length L = $\lambda/2$. The edge admittance consist equivalent conductance G_e and susceptance B_e . The feed point is located L_1 distance away from edge. Input admittance y_{in} at the end of a L length long transmission line with characteristic admittance $y_o$can be given by equation

$$y_{in} = y_0 \frac{y_l + jy_0 \tan(BL)}{y_0 + jy_l \tan(BL)}$$

Where β is the phase constant. Using the above equation the input impedance at the driving point can be expressed by:

$$y_{driving\ point} = y_0 \left(\frac{y_e + jy_0 \tan(BL_1)}{y_0 + jy_e \tan(BL_1)} + \frac{y_e + jy_0 \tan(BL_2)}{y_0 + jy_e \tan(B2)}\right)$$

The total input admittance at the corner of patch is:

$$y_{in} = 2y_e$$

Where,

$$y_e = B_e + G_e$$

Approximated values of G_e and B_e can be given by

$$G_e = 0.00836\frac{W}{\lambda_0}$$

$$B_e = 0.01668\frac{\Delta L}{h}\frac{W}{\lambda_0}\varepsilon_{reff}$$

At the resonance the imaginary parts of the edge admittance are equal and out of phase and they will cancel out each other. So the total input admittance at the edge at resonance become real and is equal to

$$y_{in} = 2G_e$$

So at the resonance the total input impedance become pure real.

$$R_{in} = \frac{1}{2G_e}$$

When we consider the mutual conductance into account then the input resistance will become

$$R_{in} = \frac{1}{2(G_e \pm G_{12})}$$

$$G_{12} = \frac{1}{120\pi^2}\int_0^{\pi}\left[\frac{\sin(\frac{k_0 w}{2}cos\theta)}{cos\theta}\right]^2 J_0(k_0 L sin\theta) sin^3\theta d\theta$$

Using the model expansion analysis the input resistance at a point y_0 away from the edge of patch along the centre line can be calculated by the formula:

$$R_{in(y=y_0)} = \frac{1}{2(G_e \pm G_{12})} \quad cos^2(\frac{\pi}{L} y_0)$$

$$= R_{in(y=0)} \, cos^2(\frac{\pi}{L} y_0)$$

A graph below shows that the input impedance of the rectangular patch antenna varies according to square of cosine, which shows that the input resistance is maximum at the corner of patch and it is zero at the centre of patch.

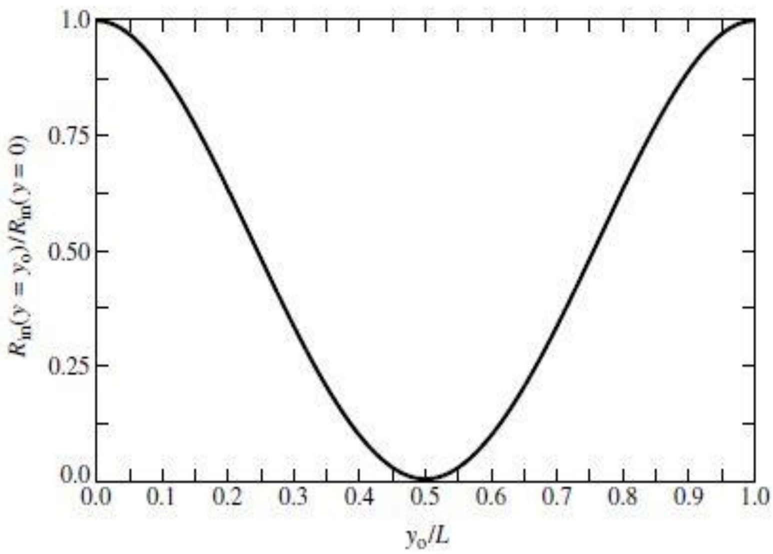

Figure 4. 6 Normalized Input Resistance

4.1.1b) ***<u>Cavity Modal</u>***

The cavity model first described by Lo et al. in late 1970s. As the name says Cavity model treated the rectangular patch antenna as a cavity with electric walls above and below at metallic patch and ground plane, and magnetic walls along the edges of patch [14,15]. The field under the patch is the summation of the resonance modes created by these radiating walls. The cavity model based on the assumption that only z-axis component of electric field and x and y axis components of magnetic field exist. A simple rectangular antenna used for the calculation in cavity model is shown in figure.

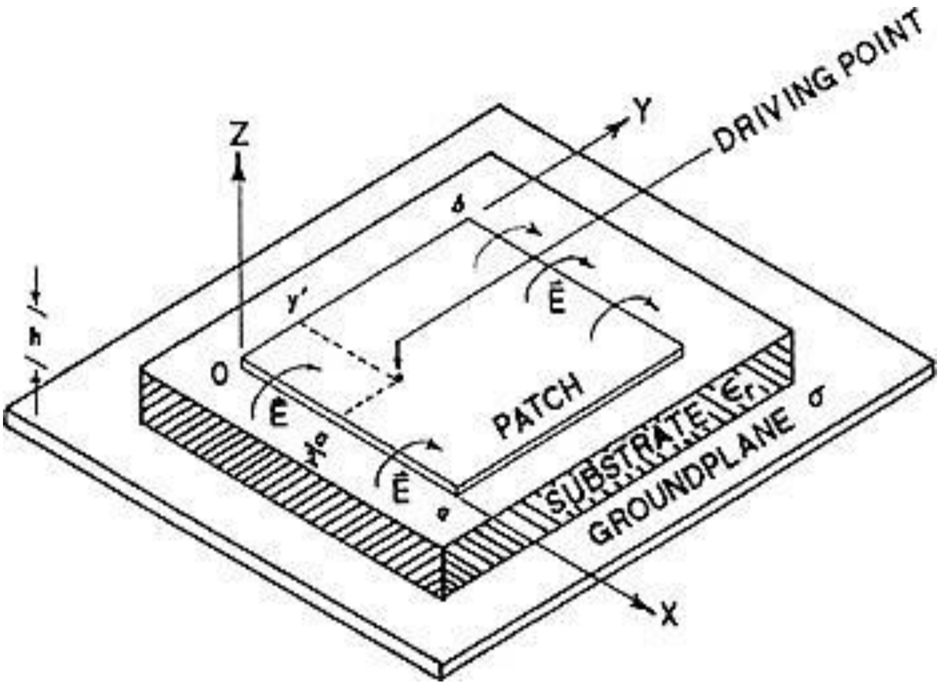

Figure 4. 7 Rectangular Patch for cavity Model

The electric field below the patch at a point x,y can be given by expression below:

$$E_z = \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} A_{mn} \emptyset_{mn}(x,y)$$

$$A_{mn} = j\omega\mu \frac{< J_z, \emptyset_{mn} >}{< \emptyset_{mn,} \emptyset_{mn} >} \left(\frac{1}{k_c^2 - k_{mn}^2} \right)$$

$$\emptyset_{mn}(x,y) = cos\left(\frac{mnx}{a_{eff}}\right) cos\left(\frac{n\pi y}{b_{eff}}\right)$$

Due to the fringing fields the cavity walls are somewhat larger than the actual length. Therefore by considering the fringing effects from edges the length and width becomes:

$$a_{eff} = a + 2\Delta$$

$$b_{eff} = b + 2\Delta$$

$$k_c^2 = \varepsilon_r(1 - j\delta_{eff})k_0^2$$

$$k_{mn}^2 = cos\left(\frac{mn}{a_{eff}}\right) + \left(\frac{n\pi}{b_{eff}}\right)$$

The driving or feed point impedance at a point x,y can be given by

$$Z_{drv} = \sum_{m=0}^{\infty}\sum_{n=0}^{\infty}\frac{j\omega\alpha_{mn}}{\omega_{mn}^2-(1-j\delta_{eff})\omega^2}$$

$$\omega_{mn} = \frac{c_{0k_{mn}}}{k_{mn}}$$

$$\propto_{mn} = \frac{h\delta_m\delta_n}{a_{eff}b_{eff}\varepsilon_0\varepsilon_r}cos^2\left(\frac{m\pi x'}{a_{eff}}\right)cos^2\left(\frac{n\pi y'}{b_{eff}}\right)cos^2\left(\frac{m\pi w_p}{2a_{eff}}\right)$$

where $w_p$is width of feedline cable

$$\delta_i = \begin{cases}1 \; if \; i = 1\\ 2 \; if \; i = 2\end{cases}$$

The effective loss tangent related to dielectric loss, conduction loss, radiation loss and surface wave loss

$$\delta_{eff} = \frac{1}{Q_T} = \frac{1}{Q_d} + \frac{1}{Q_c} + \frac{1}{Q_r} + \frac{1}{Q_{sw}}$$

$$Q_d = \frac{1}{tan\delta}$$

$$Q_c = \frac{1}{2}\,\eta_0\mu_r\left(\frac{k_0 h}{R_s}\right)$$

$$R_s = \sqrt{\frac{\omega\mu_0}{2\sigma}}$$

$$Q_r = \frac{2wW_{es}}{p_r}$$

here W_{es} refers to energy stored

$$W_{es} = \frac{\varepsilon_0\varepsilon_r abV_0^2}{8h}$$

The radiated power $$P_{rad} = \frac{V_{0A}^2\pi^4}{23040}\left[(1-B)\left(1-\frac{A}{15}+\frac{A^2}{420}\right)+\frac{B^2}{5}\left(2-\frac{A}{7}+\frac{A^2}{189}\right)\right]$$

$$A = \left(\frac{\pi a}{\lambda_0}\right)^2$$

$$B = \left(\frac{\pi b}{\lambda_0}\right)^2$$

The Q_{sw} in form of radiation quality factor Q_r

$$Q_{sw} = Q_r\,\frac{e_r^{hrd}}{1-e_r^{hed}}$$

Where $$e_r^{hrd} = \frac{p_r^{hrd}}{p_r^{hrd}+p_r^{hrd}}$$

$$p_r^{hrd} = \frac{(k_0h)^2(80\pi^2\mu_r^2c_1)}{\lambda_0^2}$$

$$c_1 = 1-\frac{1}{n_1^2}+\frac{2}{5n_1^4}$$

$$n_1 = \sqrt{\varepsilon_r\mu_r}$$

$$p_{sw}^{hed} = \frac{\eta_0 k_0^2}{8} \frac{\varepsilon_r\left(x_0^2-1\right)^{3/2}}{\varepsilon_r(1+x_1)+hk_0\sqrt{x_0^2-1}\left(1+\varepsilon_r^2 x_1\right)}$$

$$x_1 = \frac{x_0^2-1}{\varepsilon_r - x_0^2}$$

$$x_0 = 1 + \frac{-\varepsilon_r^2+\alpha_0\alpha_1+\varepsilon_r\sqrt{\varepsilon_r^2-2\alpha_0\alpha_1+\alpha_0^2}}{\left(\varepsilon_r^2-\alpha_1^2\right)}$$

$$\alpha_0 = \sqrt{\varepsilon_r - 1}\tan(k_0 h\sqrt{\varepsilon_r - 1})$$

$$\alpha_1 = -\left[\frac{\tan\left(k_0 h\sqrt{\varepsilon_r-1}\right)+\frac{k_0 h\sqrt{\varepsilon_r-1}}{cos^2(k_0 h\sqrt{\varepsilon_r-1})}}{\sqrt{\varepsilon_r-1}}\right]$$

The cavity model is more accurate as compared to transmission line model but it is based on many assumptions and approximations that is effective only for electrically thin substrate.

4.2)Circular Microstrip Antenna

Circular patch is the second most widely used geometry for the microstrip patch antenna. As in rectangular microstrip antenna we have two degree of freedom (length and width) to control the antenna characteristics, here we have only radius of circular patch. A circular microstrip antenna is shown in figure below.

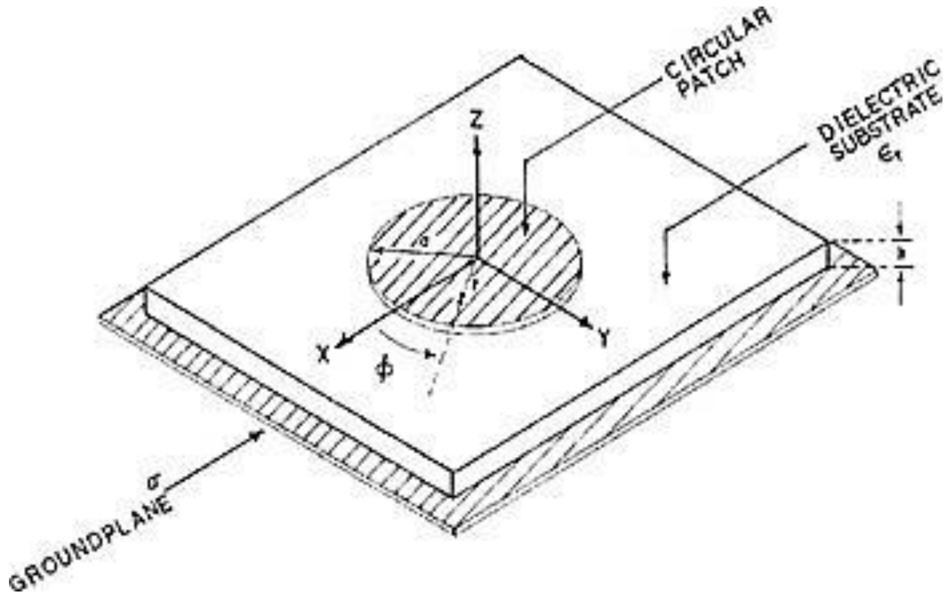

Figure 4. 8 Circular Patch Antenna

As shown in figure Metallic Circular patch with radius a is placed a height h above the ground plane. Dielectric substrate separates the patch and ground plane and the patch is fed at a point r distance from the centre at a angle ϕ from the x-axis. The circular patch antenna can be analysis by considering the patch as a cavity with two perfect conductor electric wall above and below (patch and ground plane) and magnetic walls along the edges. The electric field below the circular patch can be given by:

$$E_z = E_0 J_n(kr) cos(n\emptyset)$$

And the magnetic field components can be given by:

$$H_r = -\frac{j\omega\varepsilon n}{k^2 r} E_0 J_n(kr)\sin(n\varphi)$$

$$H_\phi = -\frac{j\omega\varepsilon}{k} E_0 j_n'(kr)\cos(n\varphi)$$

Where,

k = propagation constant

J_n = nth order bessels function

j'_n = nth order derivative of bessels function

The resonance frequency f_{mn} related to TM mode can be given as:

$$f_{mn} = \frac{X_{mn}.c}{2\pi\varepsilon_{eff}\sqrt{\varepsilon_r}}$$

Where

X_{mn} = mth zero of derivative of Bessel's function of nth order

C = velocity of light in free space

a_{eff} = effective radius of circular patch

$$a_{eff} = a.\left[1 + \frac{2h}{\pi a \varepsilon_r}\left(ln\left\{\frac{\pi a}{2h}\right\} + 1.7726\right)\right]^{1/2}$$

for a\h >> 1

and the actual radius of patch can be determined by

$$a = \frac{X_{mn}.c}{2\pi\sqrt{\varepsilon_r}}.\left[1 + \frac{2h}{\pi a \varepsilon_r}\left(ln\left\{\frac{\pi a}{2f_{mn}h}\right\} + 1.7726\right)\right]^{-1/2}$$

Therefore radius of circular patch can be found using above equation. The first four Bessel function zeroes are:

Table 4. 1 Bessel Function values

T_{mn}	**1,1**	**2,1**	0,2	3,1
X_{mn}	1.84118	3.05424	3.83171	4.20119

Chapter 5

Ultra Wide Band Antennas

After declaring the ultra-wide band (UWB) from frequency band 3.1 to 10.6 GHz by Federal Communications Commission (FCC) in 2002 for the use of indoor and hand-held systems, Ultra-wideband (UWB) antennas have gained so much of interest by the researchers[17]. For an antenna to be considered ultra wideband (UWB) or not there are two criteria available on the basis of fractional bandwidth. One definition (by Defence Advanced Research Projects Agency report) requires an antenna to have fractional bandwidth greater than 0.25. An alternate and more recent definition by Federal Communications Commission (FCC) places the limit at 0.2.

$$\mathrm{BW} = 2\frac{f_h - h_l}{f_h + h_l} \geq \begin{cases} 0.25 & DARPA \\ 0.2 & FCC \end{cases}$$

The major disadvantage of microstrip antenna is narrow bandwidth. For the enhancement of impedance bandwidth, several types of techniques such as uses of high value dielectric constant[8], parasitic coupled patches[19], defected patch structure, use of metamaterial[20], stacked structure [18]and using a matching network for proper impedance matching[21] have been reported. Here in the proposed designs for broadening the impedance bandwidth of the antennas defected ground plane strategy is used. In some designs circular shape partial ground plane with an elliptical notch is used. Some designs have partial ground plane with curvy edges and a narrow rectangular slit is also used.

5.1)<u>Design 1</u>

Modified Circular Patch Antenna for UWB application

The designed antenna has two half circular patches which are overlapped to each other. A narrow rectangular slit is added to the patch to improve the performance of antenna. The proposed antenna is fabricated on an inexpensive and easily available dielectric material FR-4 with permeability of 4.4.

5.1.1)Antenna design and parameters:

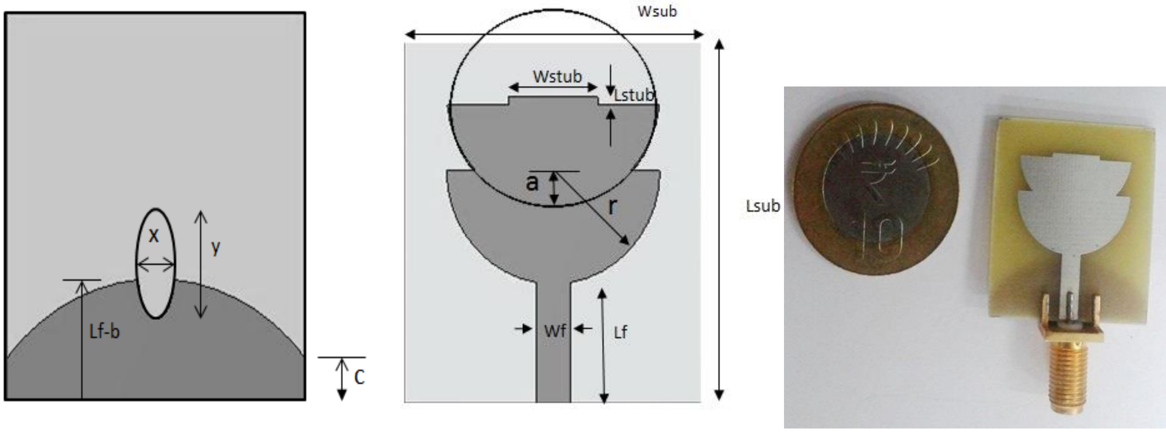

Figure 5.1. 1 Front and Back View and Fabricated Antenna

Table 5.1 Dimensions of the Proposed 1st Design

Parameters	Description	Value
r	Radius of half circular patch	9.5
a	Overlapping length	4
Lf	Length of feedline	10
Wf	Width of feedline	3.058
Lstub	Length of stub	0.7
Wstub	Width of stub	8
Lsub	Length of substrate	29.8
Wsub	Width of substrate	12.6

Proposed microstrip antenna is fed by standard 50ohm microstrip feed line. Different parameters with their Optimized value of the proposed antenna are listed below in table:

5.1.2) Simulation Results:

A circular shape partial ground plane is used in the design. To increase the bandwidth of antenna defected ground plane strategy is used. An elliptical notch is created in the ground plane, major axis and minor axis radius of which is x=1.6 and y=3.1 respectively. The s11 vs frequency curve for the optimized parameters is shown below.

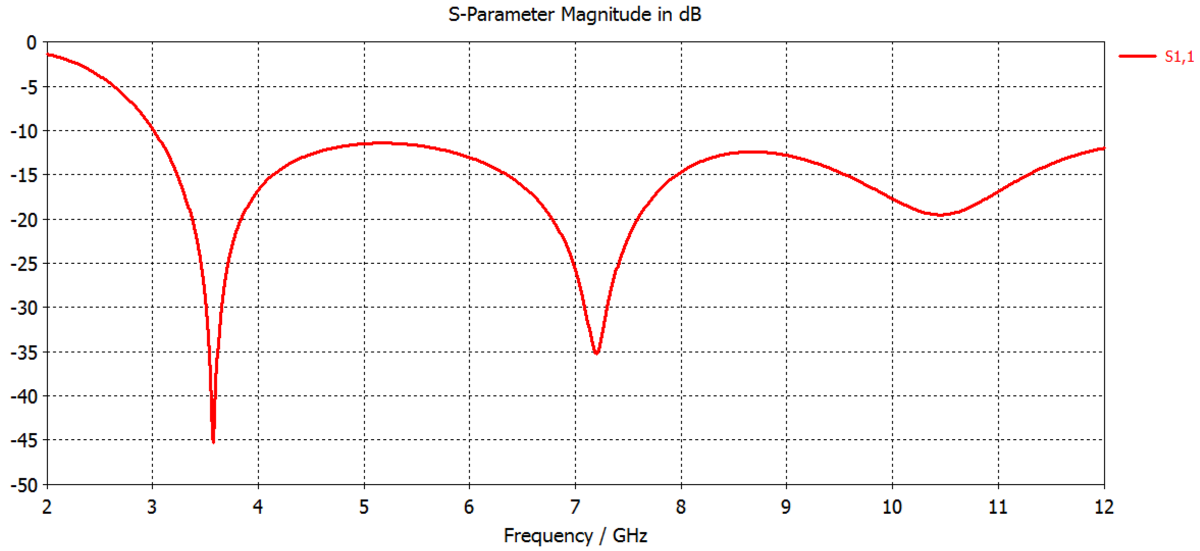

Figure 5.1. 2 frequency vs s11 curve for optimized values

The effect of modifying the radius of patch effect on s11 parameter is observed. Figure below shows different s11 vs frequency curve for different values of radius r. It is observed that when we increase the radius the s11 vs frequency curve shifts towards lower frequency while on decreasing it shifts toward right. Therefore we can conclude that the two resonance frequencies we are getting are inversely proportional to the radius of the circular patch. It is also observed that for optimum value of radius r=9 the s11 is more deep.

radius r

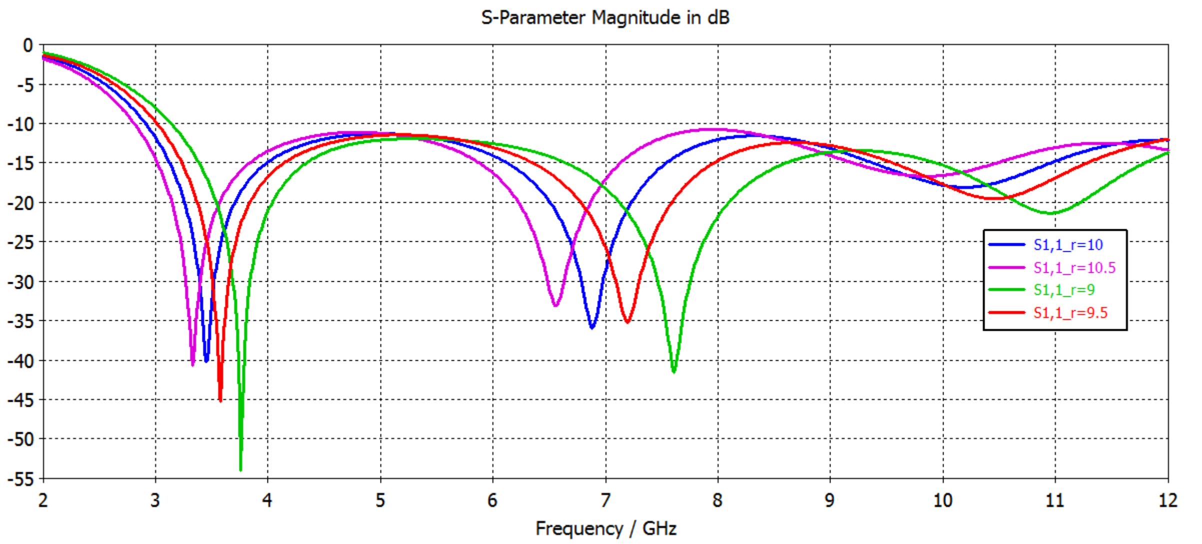

Figure 5.1. 3 frequency vs s11 curve for different values of radius r

The overlapping of circular patches also affects the antenna characteristics and the value of overlapping length a is manually optimized. Figure shows s11 results for different value of a.

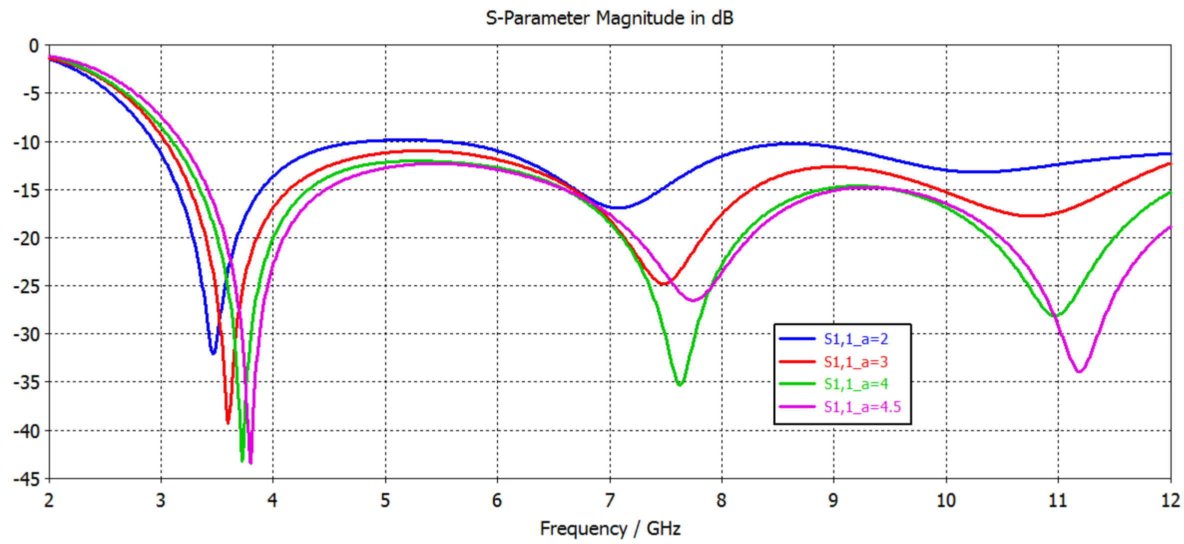

Figure 5.1. 4 frequency vs s11 curve for different values of a

From the results it is clear that when the overlapping of the patches increases or decreases from its optimum value a=4 the s11 vs frequency curve shift upward.

The figures below showing the antenna radiation pattern with principal E-plane and H-plane for different frequencies.

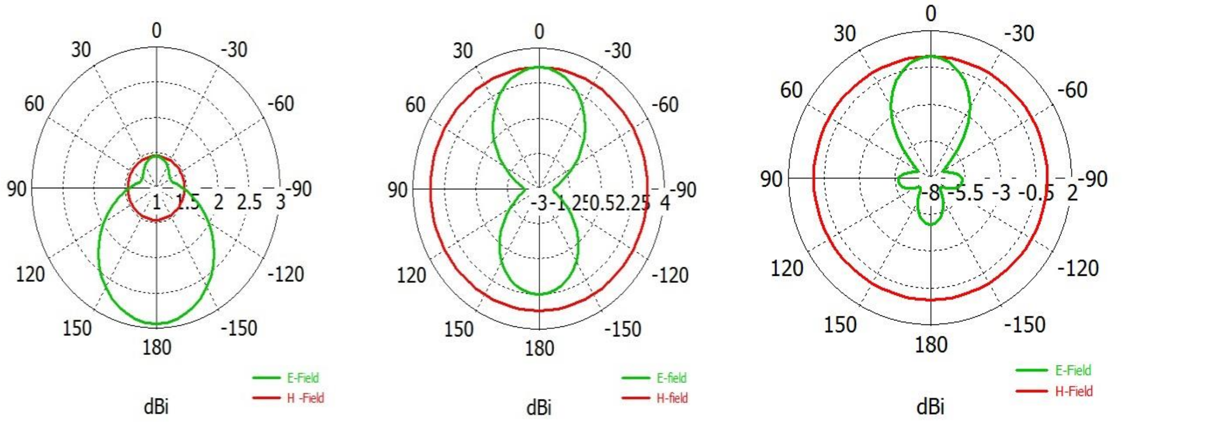

Figure 5.1. 5 Radiation Pattern for frequency 3.63, 7.63 and 9.3 respectively.

We can observe that the H-Plane patterns are omnidirectional and the E-Plane patterns have dumble shape pattern.

Figure below showing the Gain vs frequency curve. Antenna have maximum gain at 12 GHz 4.2 dB and minimum -5.6 dB and -1.1 dB at 2 GHz and 10 GHz respectively.

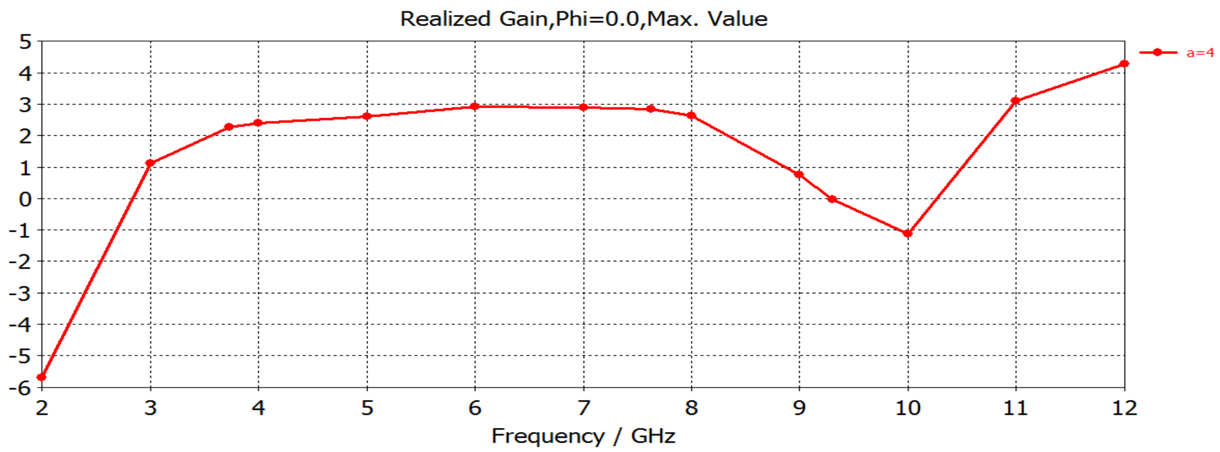

Figure 5.1. 6 Realized Gain vs Frequency plot

5.2)*Design 2*

Elliptical Shape Microstrip Patch Antenna with Modified Groundplane

The second design is elliptical patch antenna with modified ground plane. FR-4 dielectric material is used as substrate with dielectric constant 4.4. Standard 50 ohm microstrip feedline is used to feed. The results show that the proposed antenna has the bandwidth (vswr=2) from 2.46 Ghz to 13.62 Ghz which covers the UWB band therefore the proposed antenna is a good candidate to be used for the UWB application. Partial ground plane is used here. For increasing the bandwidth as a ground plane strategy a rectangular notch and a narrow slit is made in the ground plane.

5.2.1) Antenna design and parameters:

The front and back view of the proposed antenna is shown below. Structural view showing all the antenna parameters. Partial ground plane with curvy edges is used. Making a rectangular notch behind the feedline in ground plane and narrow rectangular slit in ground results in drastically improvement in the return loss curve.

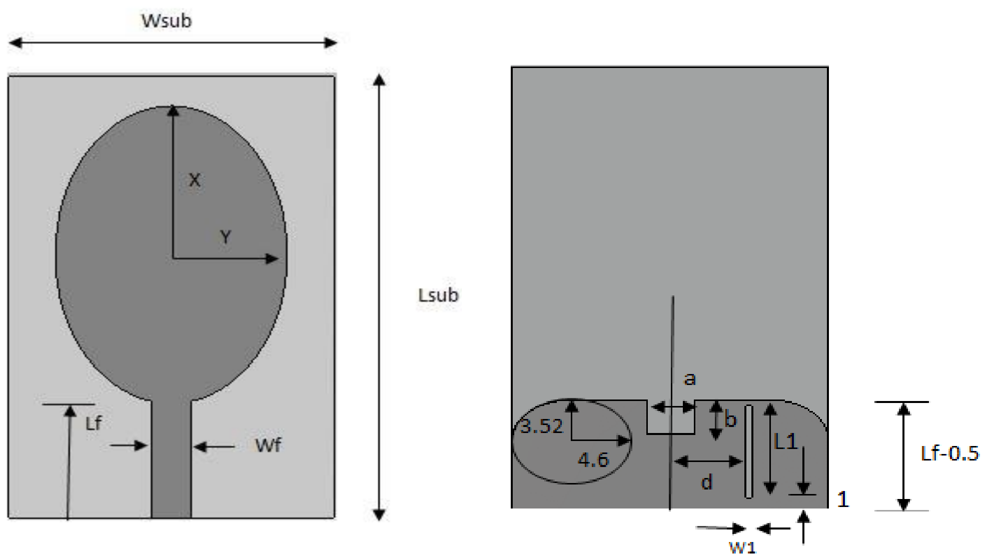

figure 5.2. 1 front and back view of proposed antenna

Parameter list with their values are written in the table below. All the dimensions are in millimetre.

Table 5.2 Dimensions of the Proposed 2nd Design

Parameters	Description	Optimized Value
X	Minor radius of ellipse	9
Y	Major radius of ellipse	13
Lf	Length of the feedline	10
Wf	Width of the feedline	3.058
Lsub	Length of the substrate	38.6
Wsub	Width of the substrate	25.2
a	Length of notch	3.4
b	Width of notch	3.858
L1	Length of rectangular slit	8
W1	Width of rectangular slit	0.5

5.2.2) Simulation Results:

The Graph below showing that how the return loss curve is improved by making a number of modifications in the ground plane.

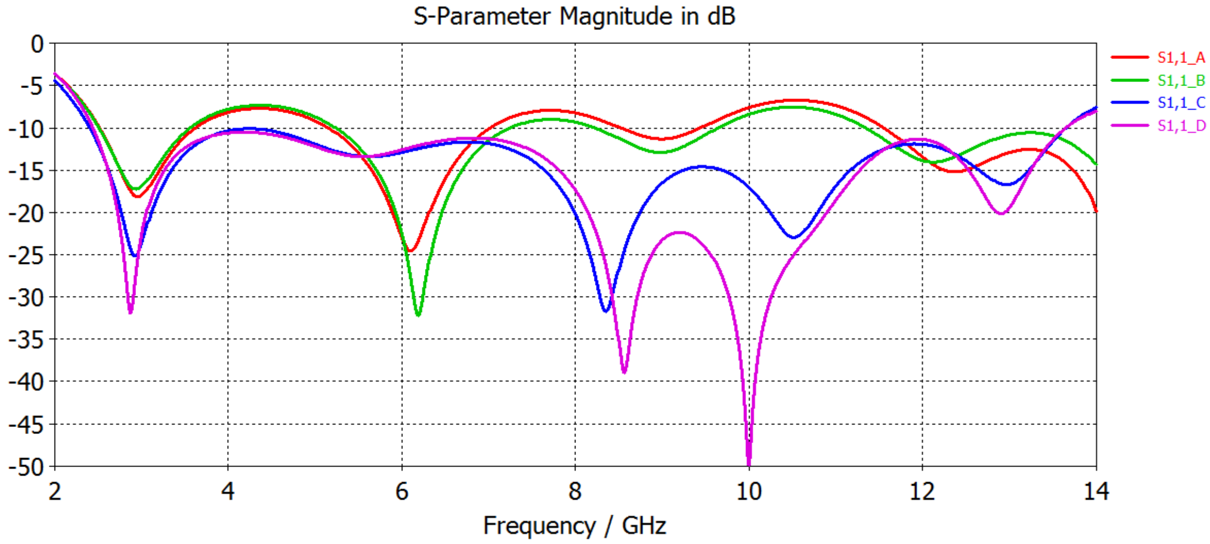

figure 5.2. 2 Return loss curve for different modifications in ground.

Where,

s_{11}_A = s_{11} of antenna with rectangular partial ground plane.

s_{11}_B = s_{11} of antenna with partial ground plane with curve at edges.

s_{11}_C = s_{11} of antenna with partial ground plane with curve at edges and notch.

s_{11}_D = s_{11} of antenna with partial ground plane with curve at edges, notch and slit.

From graphs it can be observe that making the edges of rectangular ground plane smooth will not affect the return loss curve in lower frequency but at higher frequency it improves the return loss curve, the return loss curve shifts downside. By making a rectangular notch in ground plane just below the feedline results in drastically increase in the bandwidth. By introducing a narrow rectangular slit curve moves further downside.

The return loss curve for different position of rectangular slit related to centre line is also observed. It is observed that changing the relative position of the slit not affects so much in lower frequency but effects on higher frequency.

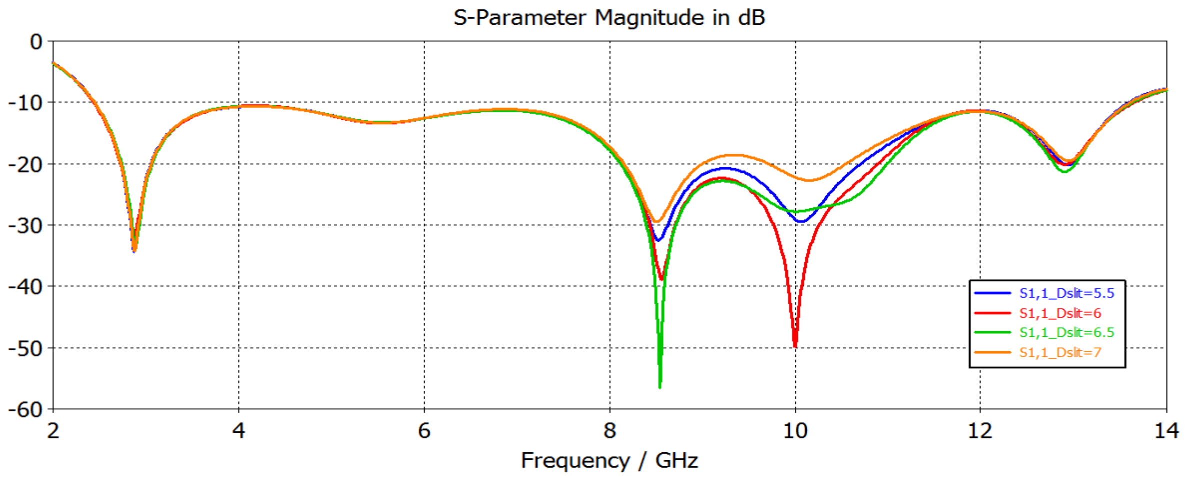

figure 5.2. 3 Return loss curve for different position of slit.

Effect of length and width of rectangular notch on the return loss curve is also shown in figure.

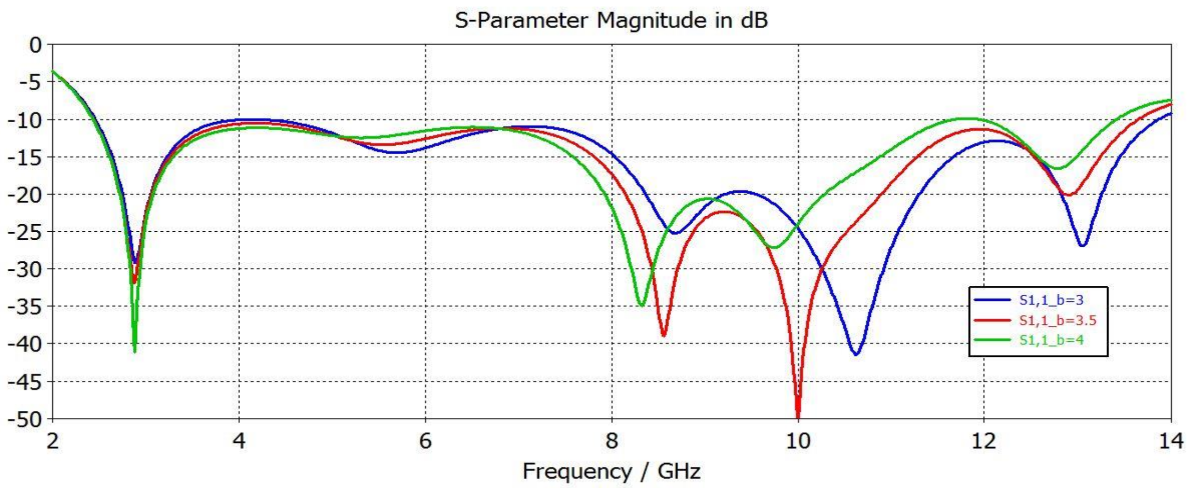

figure 5.2. 4 Return loss curve for different value of notch length b

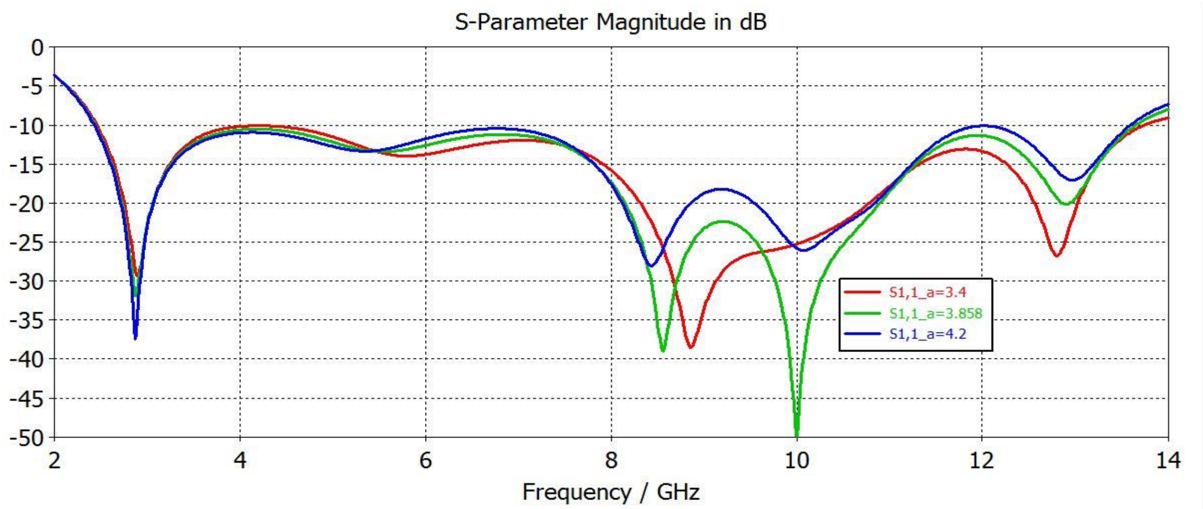

figure 5.2. 5 Return loss curve for different value of notch width a

From the above two graphs it is observed that the effect of notch dimension on return loss curve is more for the higher frequency as compared to lower frequencies. The radiation pattern of proposed antenna for different frequency is shown below. The H-plane pattern is shown in the broad side direction which are almost omnidirectional and E-plane patterns have lobes shown in figure.

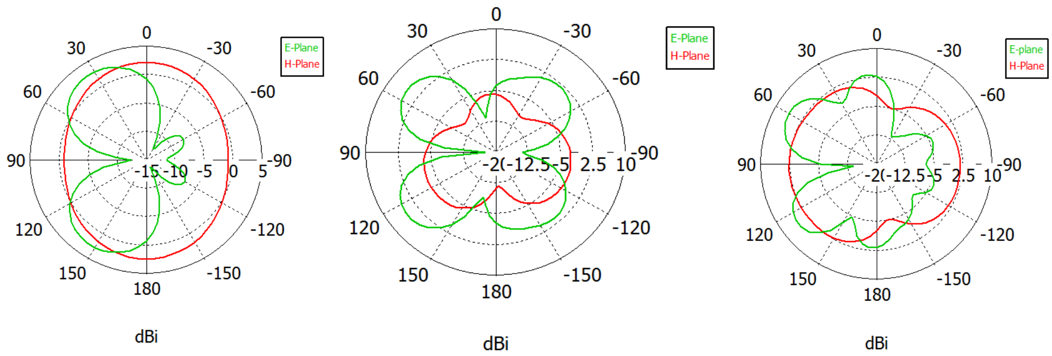

figure 5.2. 6 Radiation Pattern for frequency 5.58, 8.56 and 10 respectively.

The realized gain plot are shown below, With maximum 4dB at 11GHz and minimum -4dB at 8GHz.

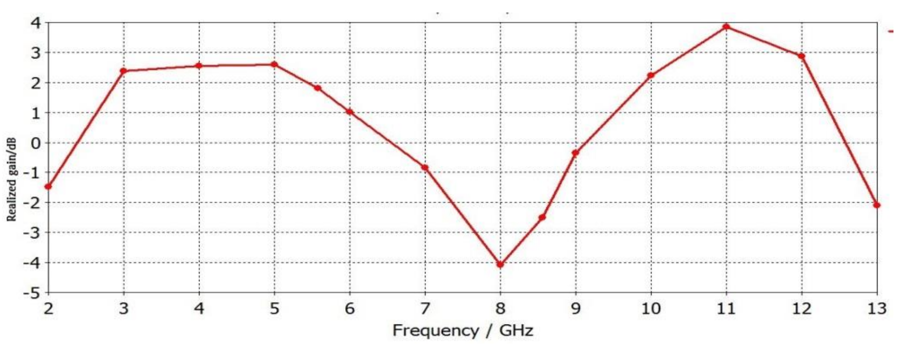

figure 5.2. 7 Realized Gain vs Frequency plot

5.3)Design 3

Extended Circular Planar Antenna For UWB application

The proposed antenna geometry is shown in the figure. Design consists of a half circular patch which is extended an extra length. Antenna is fabricated on FR-4 material and microstrip feed line is used for feeding. A circular shape partial ground plane is used with an elliptical notch just below the feedline. The simulation results show that the antenna fulfils the requirement of UWB antenna.

5.3.1) Antenna design and parameters:

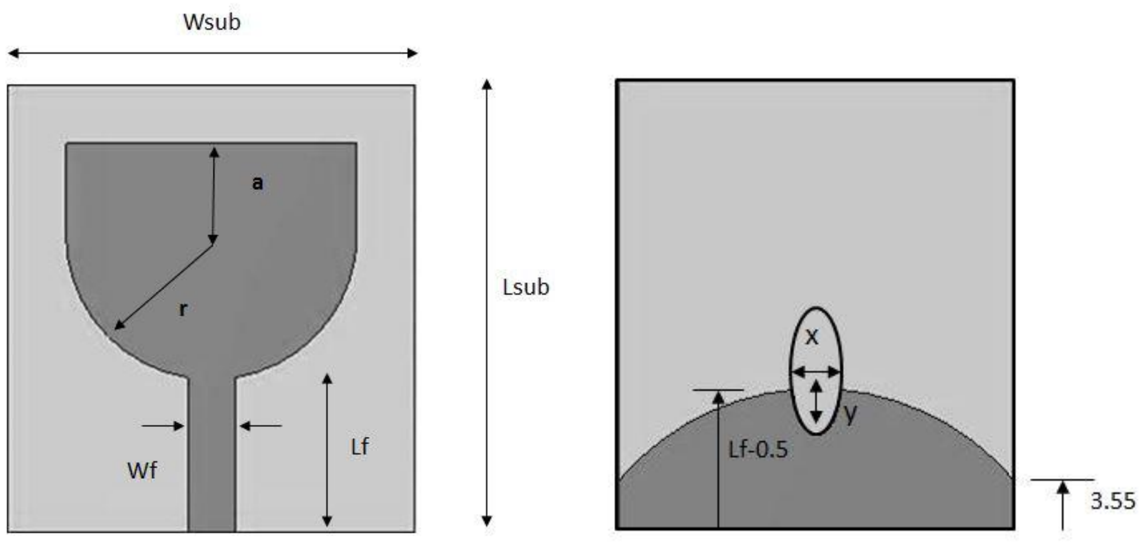

Figure 5.3. 1 front and back view of proposed antenna

Parameter list with their values are written in the table below. All the dimensions are in millimetre.

Table 5. 3 Dimensions of the Proposed 3rd Design

Parameters	Description	value
r	Radius of circular patch	9.5
a	Patch Extension	6
X	X-radius of elliptical Notch	1.6
Y	Y-radius of elliptical Notch	3.1
Lf	Length of Feedline	10
Wf	Width of Feedline	3.058
Wsub	Width of Substrate	26.6
Lsub	Length of Substrate	29.3

5.3.2) Simulation Results:

The s11 vs frequency curve with the optimized values is shown below. This shows that the proposed antenna covers the entire UWB.

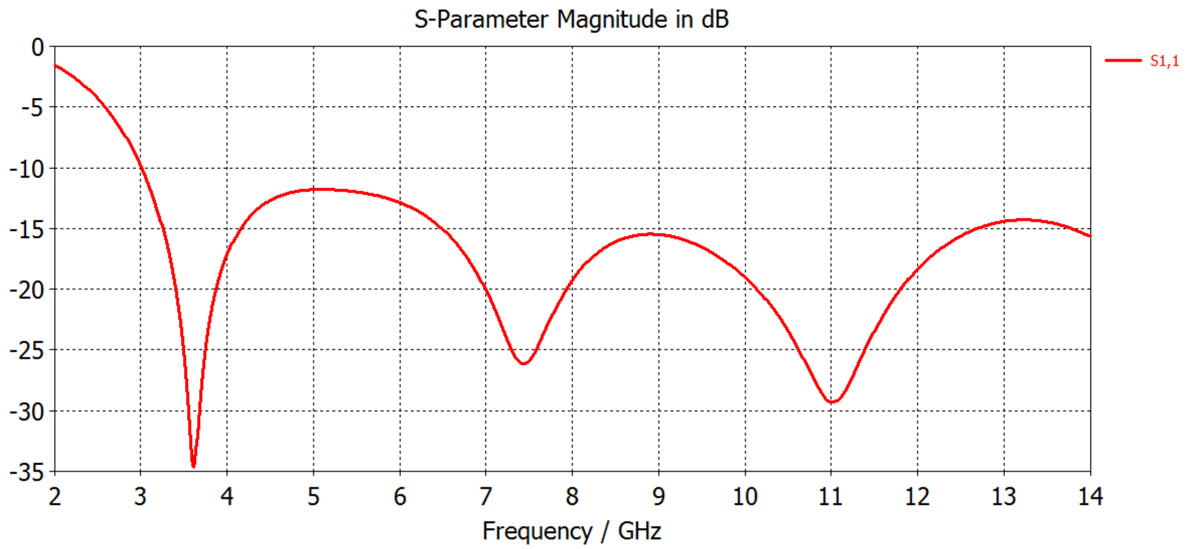

Figure 5.3. 2 Return loss vs frequency curve of proposed antenna.

Variation in the return loss curve with the patch extension length a is also observed. Figure below shows the return loss curve for different values of a.

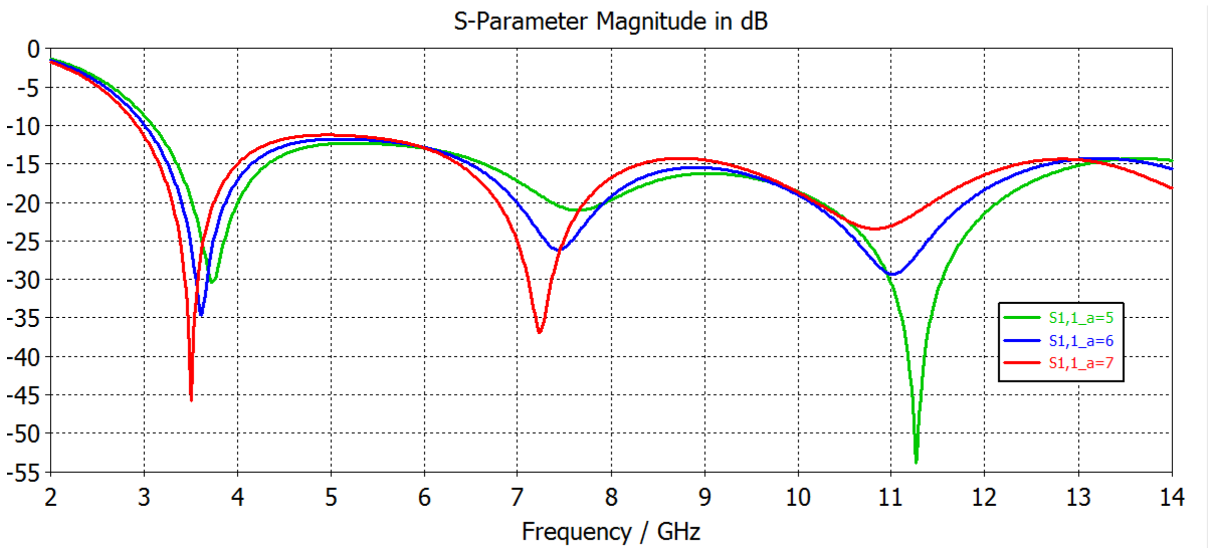

Figure 5.3. 3 Return loss vs frequency curve for different values of a.

Radiation pattern with principal E-plane and H-plane for the different frequencies are shown in figure.

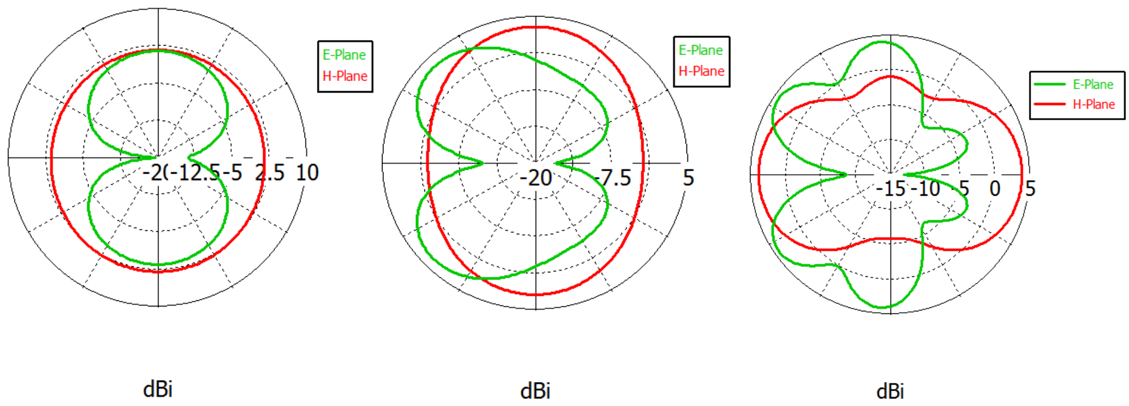

Figure 5.3. 4 Radiation Pattern for frequency 3.63, 7.45 and 11.03 respectively.

The realized gain plot are shown below with maximum 5db at 12 Ghz and minimum 0.2 dB and -5dB at 10 and 2 GHz respectively.

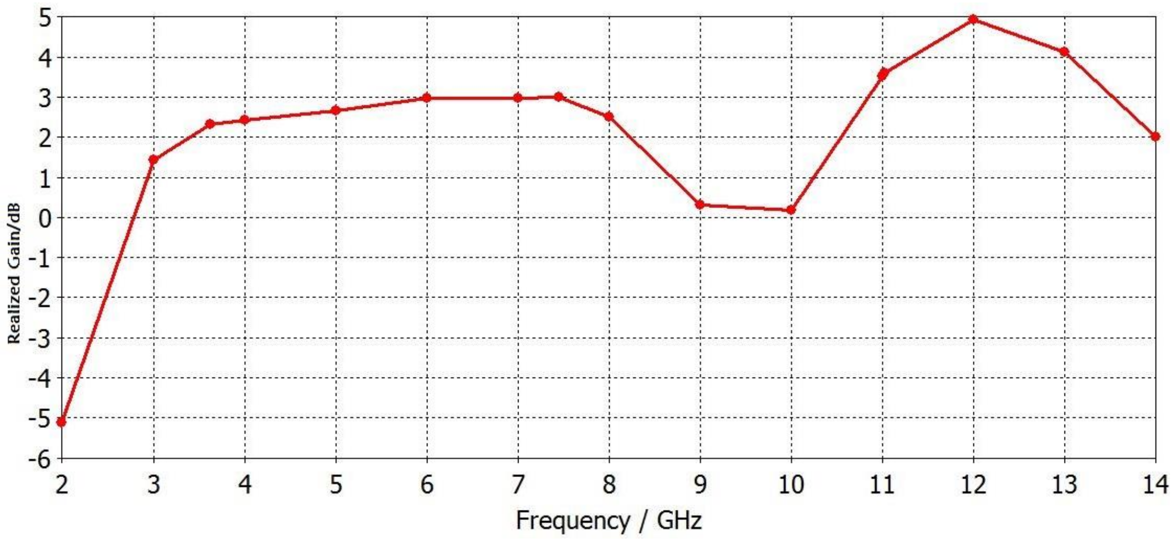

Figure 5.3. 5 Realized Gain vs Frequency plot

5.4)Design 4

Candy Shape Microstrip Patch Antenna With Modified Groundplane

This design consists of a candy shape patch. Fabricated on FR-4 substrate material and standard microstrip feedline is used for feeding. In order to get greater bandwidth modified ground plane with a rectangular notch below the feedline and a rectangular slit on the ground plane is used in the proposed design. The structural diagram of front and back view of antenna is shown below.

5.4.1) Antenna design and parameters:

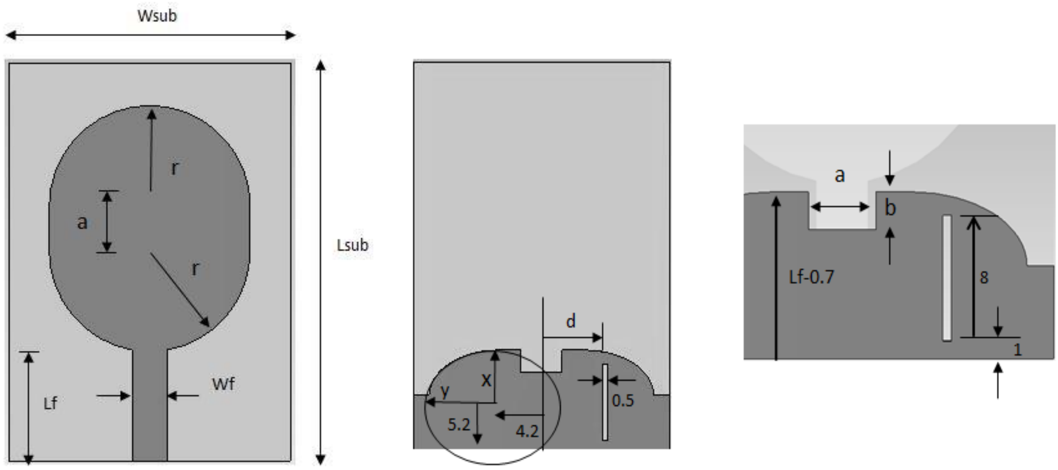

Figure 5.4. 1 Structural diagram of antenna

Different Parameters used, with their values are written in the table below. All the dimensions are in millimetre.

Table 5. 4 Dimensions of the Proposed 4th Design

Parameter	Description	value
r	Radius of the circles	9
a	Distance between circles center	4
x	Lower radius of ellipse	4.1
y	Larger radius of ellipse	6.8
Lf	Length of Feedline	10
Wf	Width of Feedline	3.058
Lsub	Length of substrate	35.6
Wsub	Width of substrate	25.2
b	Length of notch	2.1
a	Width of notch	4

5.4.2) Simulation Results:

The return loss curve of designed antenna is shown.

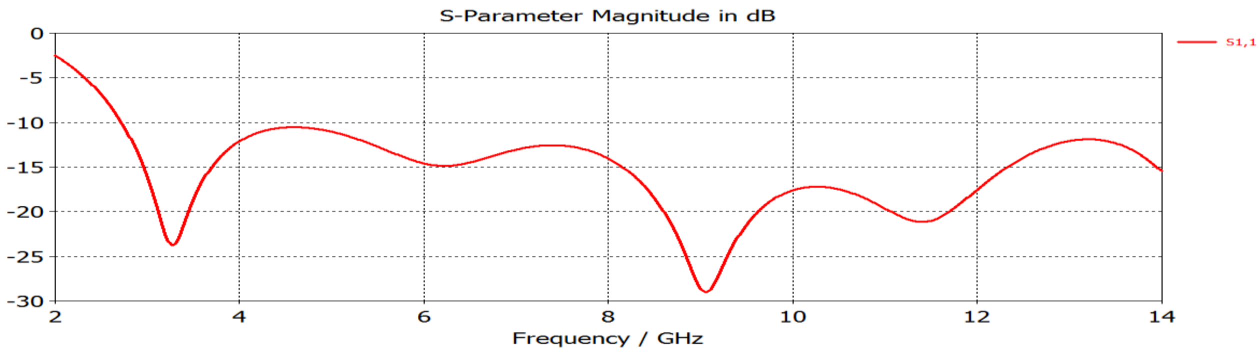

Figure 5.4. 2 Return loss vs frequency curve of proposed antenna.

Effect of the length a on the return loss curve is observed. The plot shown below shows the return loss curves for different values of a. It is seen that the effect of length a is lesser as compared to lower and higher frequency.

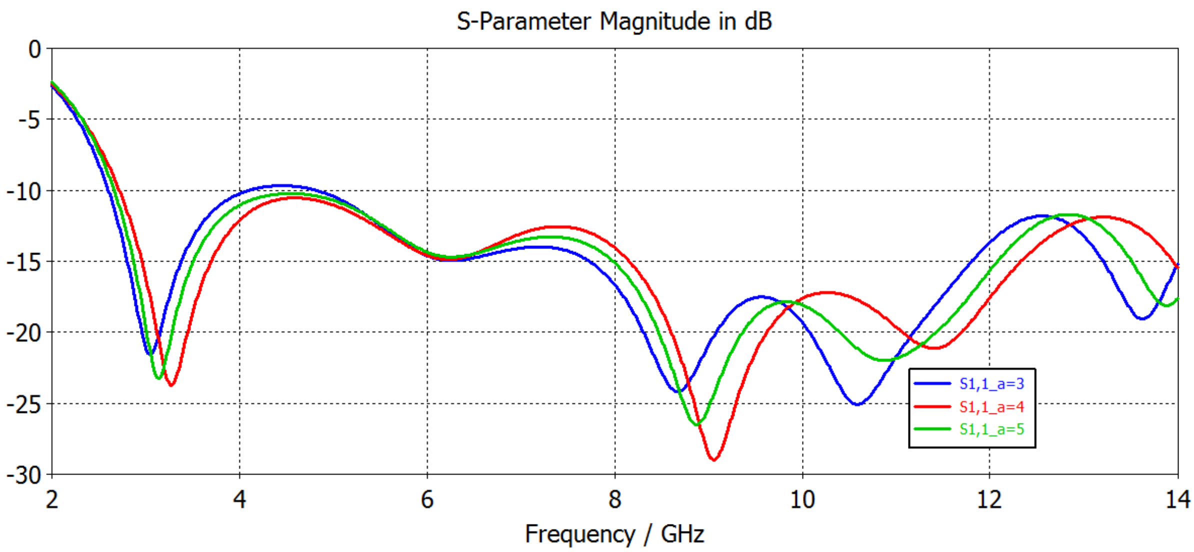

Figure 5.4. 3 Return loss vs frequency curve for different values of a

The effect of the position of rectangular slit with respect to centre line is also observed. Plot below shows the return loss curves for different value of the position d of slit. It is seen that the effect of d on return loss curve is less at the lower frequency and more at the higher frequencies.

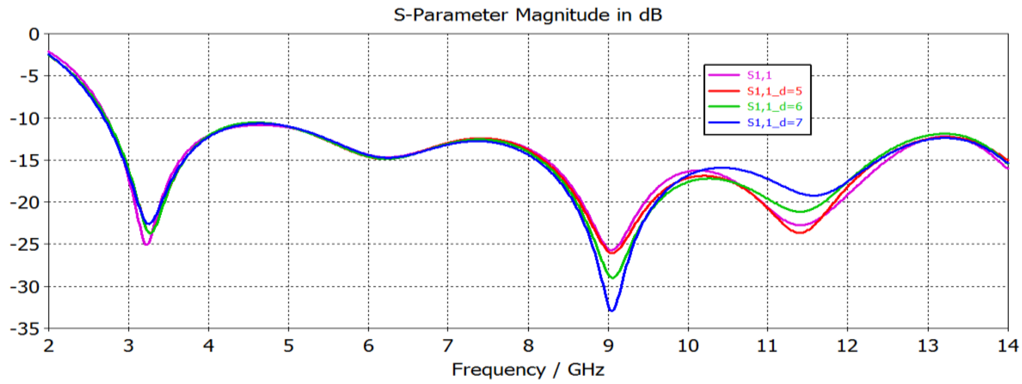

Figure 5.4. 4 Return loss vs frequency curve for different values of d

Farfield Radiation pattern with principal E-plane and H-plane for the different frequencies are shown in figure below. We can observe that the H-Plane patterns are omnidirectional and the E-Plane patterns have dumble shape pattern.

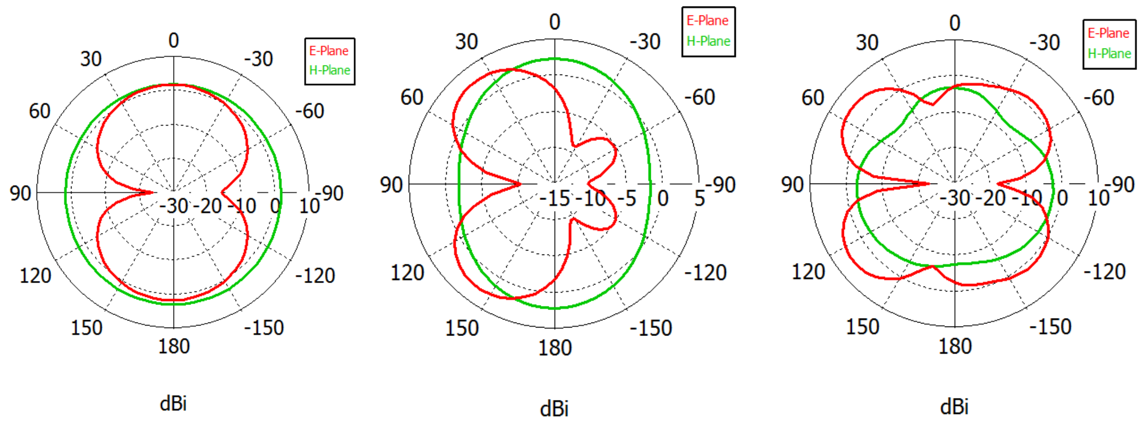

Figure 5.4. 5 Radiation Pattern for frequency 3.284, 9.06 and 11.434 respectively.

The realized gain plot are shown below. It can be observe that the antenna has maximum gain 4dB at 12 GHz and -2.8 dB minimum at 9 GHz.

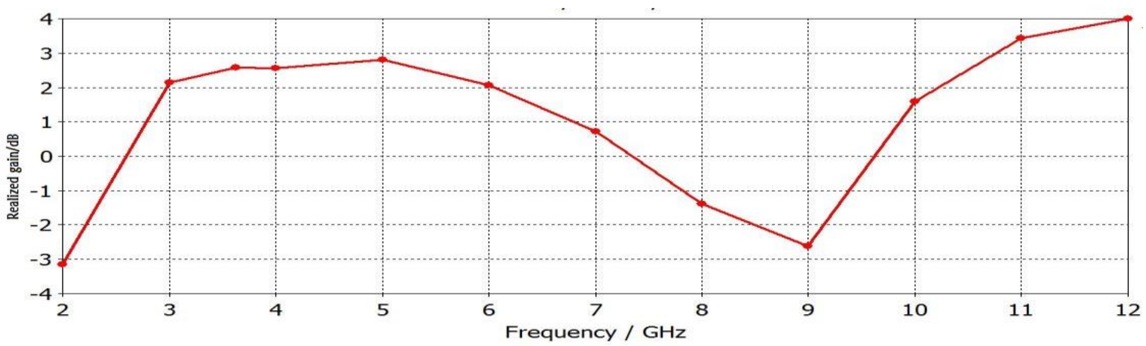

Figure 5.4. 6 Realized Gain vs Frequency plot

Chapter 6

Band Notch Ultra Wide Band Antennas

A number of applications are there which exist between the UWB frequency bands. One of the major problem for UWB systems are electromagnetic interference (EMI) from existing frequency bands, because there are many other wireless narrowband application that are allocated for different frequencies band in the UWB band, such as

- (WiMAX) operating in 3.3-3.7 GHz,
- (WLAN) for IEEE 802.11a 5.15-5.825 GHz,
- Downlink X-band satellite communication systems in 7.25 - 7.75 GHz.
- 4.5-4.8 GHz INSAT / Super-Extended C-Band (Indian National Satellite systems).

Therefore it is necessary for the designer to design the UWB antenna they can reflect the interference from the other existing bands. To overcome this interference problem UWB antennas should have band notches therefore they can reject the existing frequency bands within the ultra-wide band. Recently different types of UWB antennas having the wide bandwidth and band notch characteristics have been developed for UWB applications [1-9]. The easiest and most common method to achieve a band notch is making a narrow slot of different shapes into the radiating patch of the antenna, will affect the current flow in the patch, as demonstrated in [24]–[25]. Different type of shapes is used to make the slots (i.e., square ring and folded trapezoid, U-shape, C-shape) are used to get the band-notched in the desired frequency band. In this chapter four compact UWB antenna designs are proposed. One of the antennas has a wide bandwidth from 2.8GHz to 10.6GHz with triple band notches for rejecting the WLAN, downlink X-band satellite communication and INSAT/Super Extended C-band application respectively. A U-shape slot in the radiating patch, an open end split ring slot in patch and two C-shaped slits are used to get the proper band rejection. This proposed antenna structure’s simulation is carried out using the CAD software Microwave Studio in Computer Simulation Technology Simulator (CST), one commercial 3-D full-wave electromagnetic simulation software.

6.1)*Design 5*

A Triple Band Notch Planar Antenna For UWB Application

A half circular extended patch antenna with triple band notch characteristic for WLAN 802.11a operating in 5.15-5.85 GHz, INSAT/Super Extended C-band application (Indian National Satellite System) 4.5 to 4.8 GHz and downlink X-band satellite communication 7.25-7.75 GHz is presented. The structural diagram of front and back view of proposed antenna is shown below.

6.1.1) Antenna design and parameters:

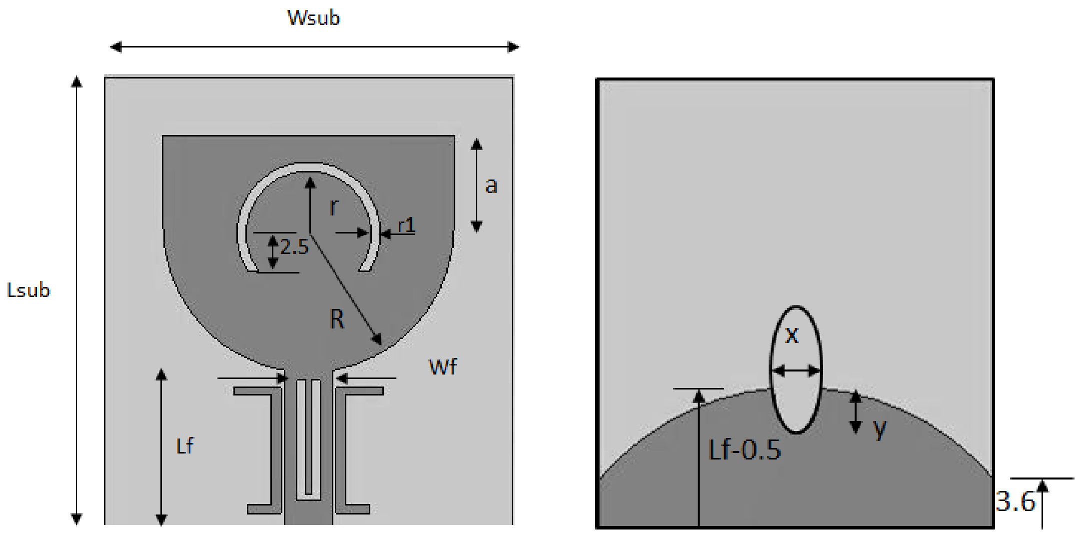

Figure 6.1. 1 front and back view of proposed antenna

As shown in figure for increasing the bandwidth of antenna a circular shape partial ground is used. An elliptical notch as a defected ground plane strategy is created in the ground plane. By creating a U-slot in transmission line first band notch 5.15–5.825 GHz for WLAN system is achieved. To reject the frequency band of 7.25–7.75 GHz two C-shaped slits are symmetrically placed besides the transmission line and to achieve band notch for 4.5-4.8 an open end ring is etched from patch. To get the band notch associated with the ring or U-slot or C-shape slit the dimensions and the relative positions has been carefully observed.

The figure below shows the dimensions of the C-shape slit and the U-slot made in the microstrip transmission line. This C-shape slits are placed very nearer to microstrip lines, just 0.271 mm besides. The spacing between the feedline and slit affects the antenna performance.

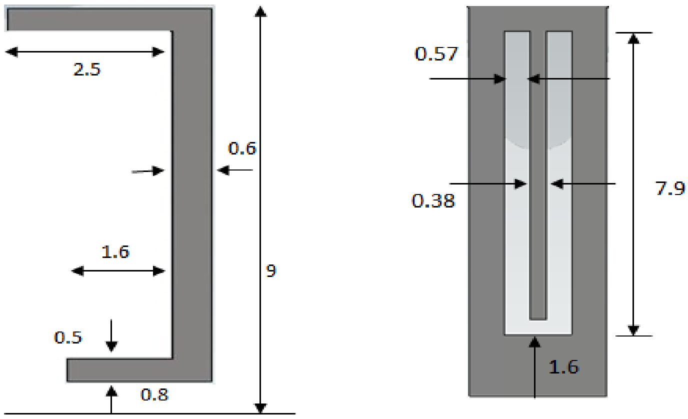

Figure 6.1. 2 U-Slot and C-shape slit

Different antenna dimensions with their descriptions and optimized values are written below in the table. All the dimensions are in millimetre.

Table 6. 1 Dimensions of the Proposed 5th Design

Parameter	Description	Value
R	Radius of circular patch	9.5
r	Radius of inner ring	4.1
r1	Width of the ring	0.6
a	Extended circular patch	6
X	x-radius of elliptical notch	1.6
Y	y-radius of elliptical notch	3.1
Lf	Length of feedline	10
Wf	Width of feedline	3.058
Lsub	Length of substrate	30.25
Wsub	Width of substrate	28.50

6.1.2) Simulation Results:

The vswr vs frequency curve for the proposed antenna with optimized parameters is shown below. We can observe from the plot that the antenna possesses three exact band notches or rejection of frequency band for three applications 4.5 to 4.8 GHz, 5.15 to 5.85 GHz and 7.25 to 7.75 GHz.

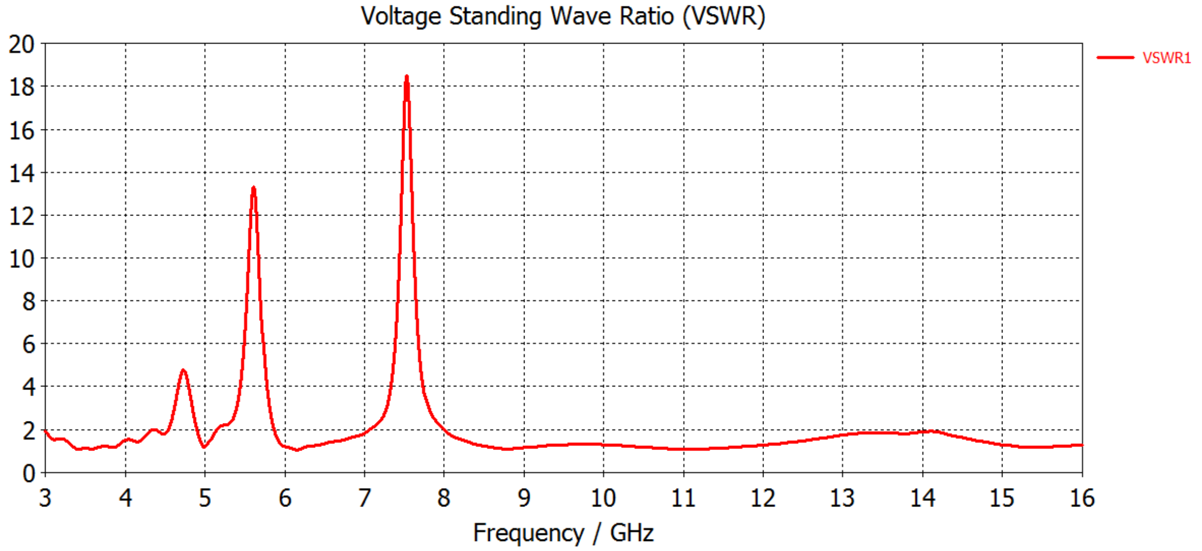

Figure 6.1. 3 VSWR vs frequency curve of Proposed Antenna.

The effect of the relative position of C-shape slit with respect to microstrip feed line is also observed. Below graph shows the comparison of different vswr curves for different values of spacing s between slits and feedline.

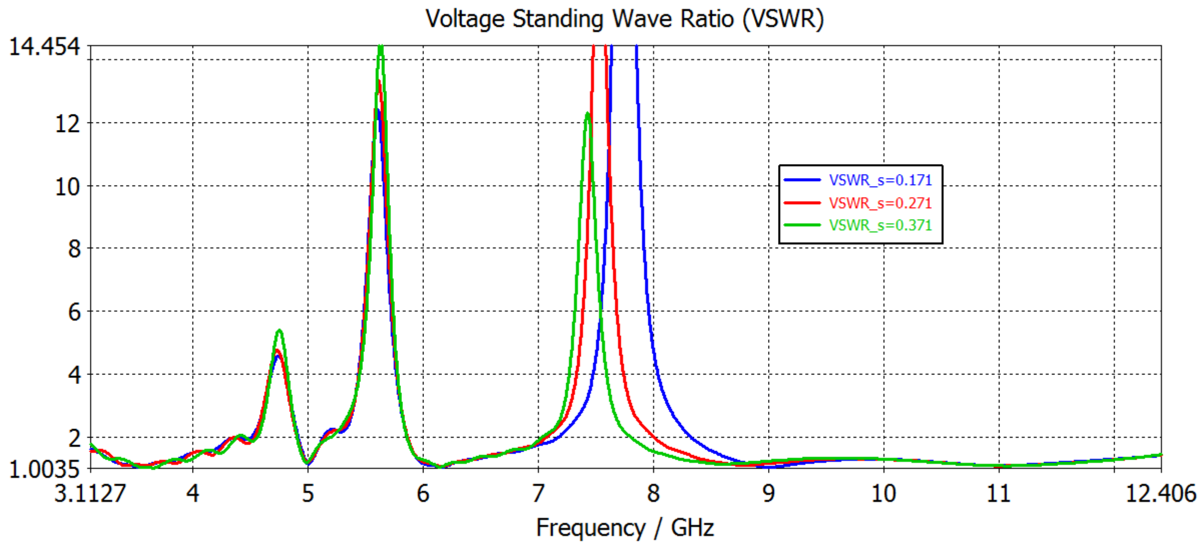

Figure 6.1. 4 VSWR vs frequency curve for different values of s spacing between slits and feed line

By plot we can conclude that the C-shape slits which responsible for band notch 7.25 to 7.75 GHz does not have so much effect on the notches created on the other two bands. Plot below shows vswr curve for the different radius of annular ring. It is observed that the effect of varying the radius of ring on other notches is negligible. It only shifts the notch frequencies that are introduce due to the annular ring notch.

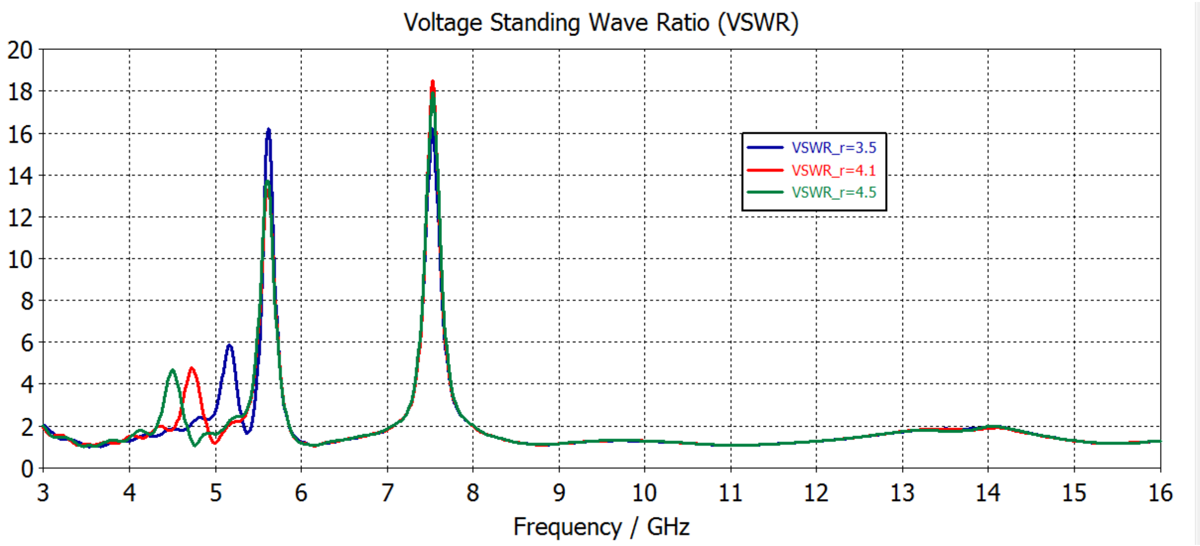

Figure 6.1. 5 VSWR vs frequency curve for different radius r of annular ring.

The plots below showing the effect of changing the dimensions length L1 and width w1 of U-shape notch on the vswr curve. We can conclude that by observing the vswr plot for different dimensions the modification only affects the frequency notch that are responsible by the notch and slit dimension.

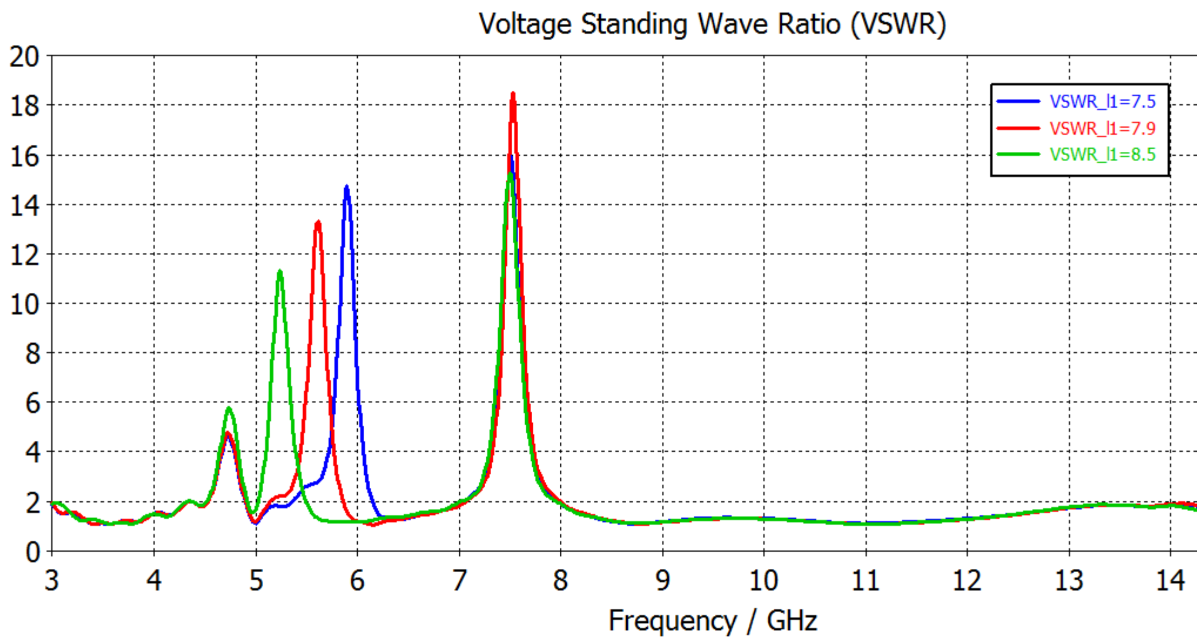

Figure 6.1. 6 VSWR vs frequency curve for different length L1 of U-shape notch.

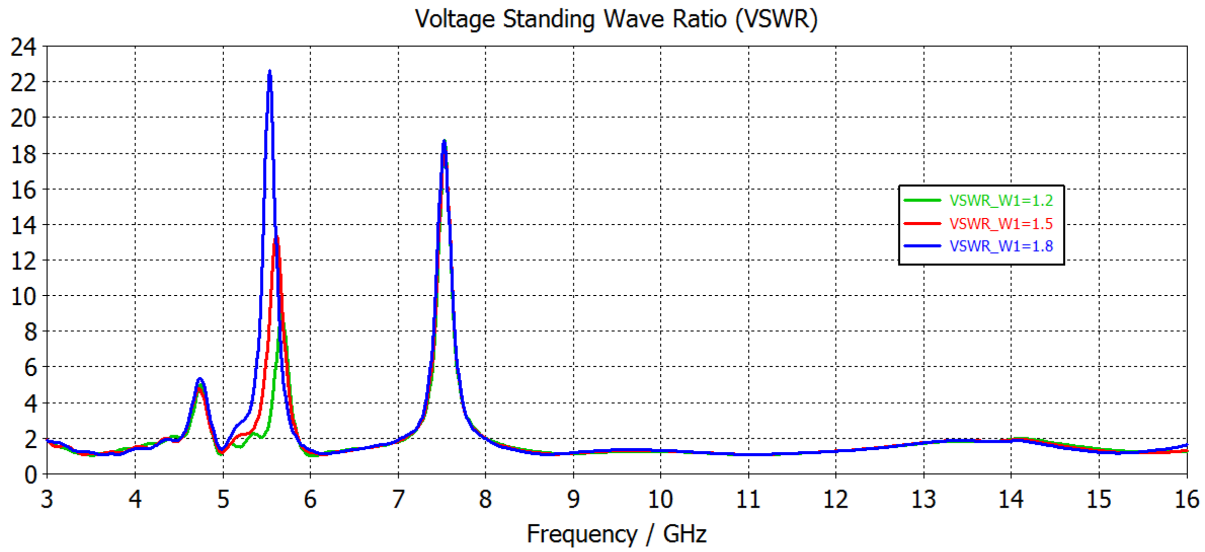

Figure 6.1. 7 VSWR vs frequency curve for different Width w1 of U-shape notch.

The Simulated results are presented, shows the usefulness of the proposed antenna structure for UWB applications. The simulation results indicate that the proposed antenna fulfils the excellent triple band notch characteristics for various frequency bands and showing the good return loss and radiation patters in the interested UWB. To get the proper band rejection the length, width and the relative positions of the slits are optimized carefully.The radiation patterns and surface current distribution for different notch frequencies are shown in below figure.

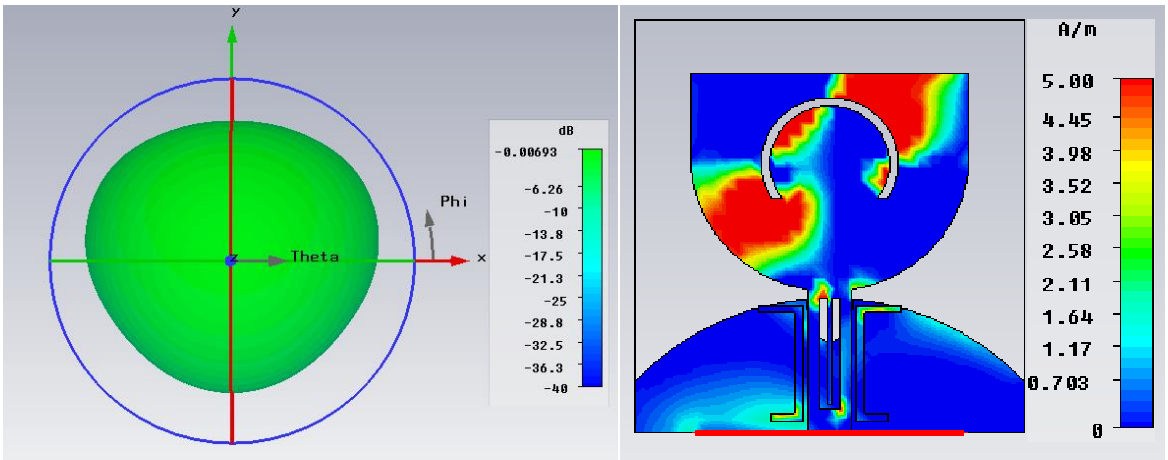

Figure 6.1. 8 Radiation pattern and Surface current distribution at 4.7GHz

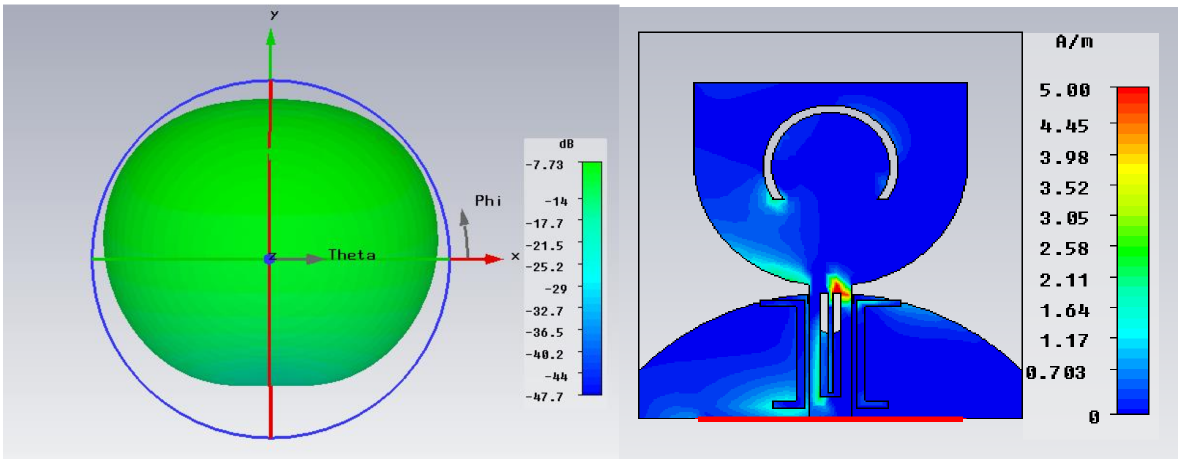

Figure 6.1. 9 Radiation pattern and Surface current distribution at 5.6GHz

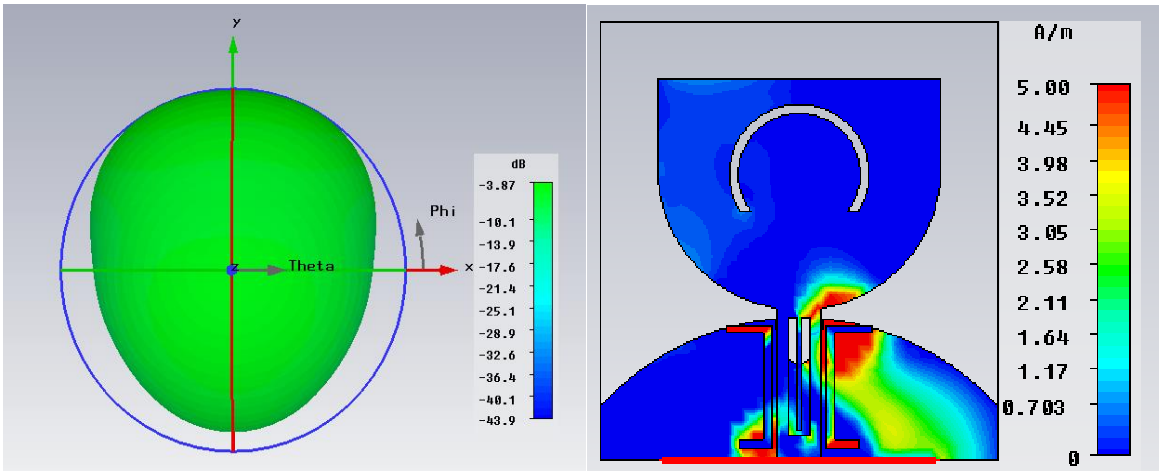

Figure 6.1. 10 Radiation pattern and Surface current distribution at 7.5GHz

It can be observe that the surface current is concentrated mainly on the notched that are responsible for band rejection at that frequency. Realized gain of designed antenna is shown in figure below, with minimum gain at the notch frequencies.

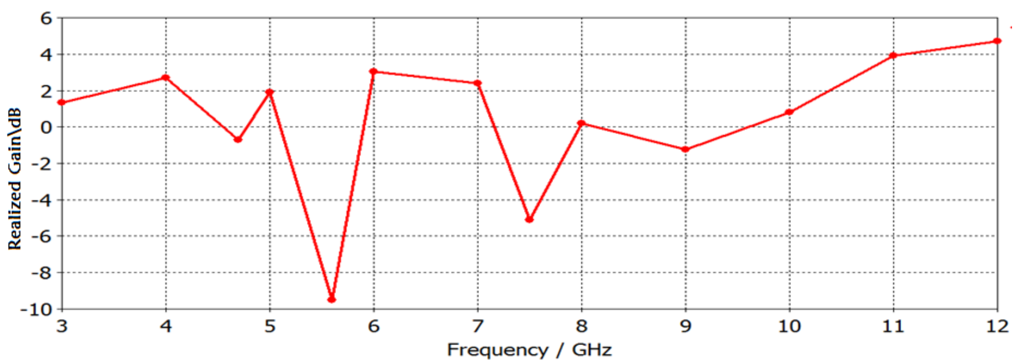

Figure 6.1. 11 Realized Gain vs Frequency plot

6.2)<u>Design 6</u>

<u>A Elliptical UWB Patch Antenna with Dual Notched Band</u>

An elliptical shape microstrip antenna with dual band notch characteristic antenna suitable for UWB application is proposed. Inverted U-shape slots are made in elliptical patch to get the band notch for WIMAX application operating in frequency band 3.3GHz to 3.7GHz and to achieve band rejection for the WLAN 802.11a band operating at frequency band 5.15 to 5.85 GHz, also an inverted U-shape slot is made in the transmission line. The simulation result shows that the designed antenna has a bandwidth (vswr<2) 2.4GHz to 11.48GHz and is a good candidate for UWB application. Figure below shows the structural diagram of designed antenna for front and back view.

6.2.1) Antenna design and parameters:

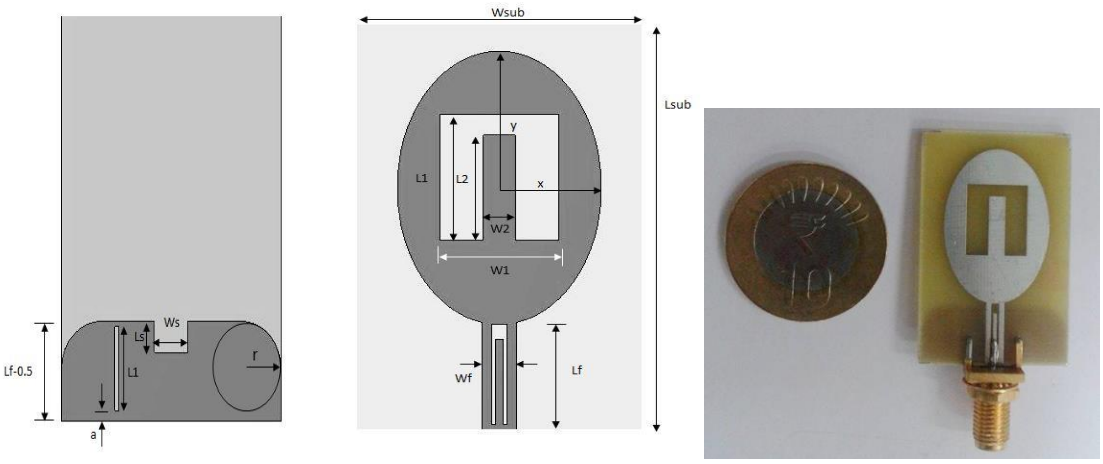

Figure 6.2. 1 front and back view of proposed antenna and fabricated antenna.

As shown in figure partial ground plane with smooth edges is used in proposed antenna. In order to increase the bandwidth of antenna defect in ground plane is made by making a rectangular notch just below the feedline and by making a narrow rectangular slit of width 0.5 in ground plane. Inverted U-slot responsible of band notch for WLAN is shown below.

Different Parameters used, with their values are written in the table below. All the dimensions are in millimetre.

Table 6. 2 Dimensions of the Proposed 6th Design

Parameter	Description	Value
X	X-radius of elliptical patch	9
Y	X-radius of elliptical patch	13
L1	Length of inverted U-slot	12
W1	Width of Inverted U-slot	10.4
L2	lower length Inverted of U-slot	10
W2	smaller width Inverted of U-slot	2.8
L3	Length of Inverted U-slot in feedline	8.5
W3	Width of Inverted U-slot in feedline	1.4
L4	Lower Length of Inverted U-slot in feedline	8.3
W4	Smaller width of Inverted U-slot in feedline	0.6
Lsub	Length of substrate	38.6
Wsub	Width of substrate	12.6
Ls	Length of rectangular notch	3
Ws	Width of rectangular notch	3.858

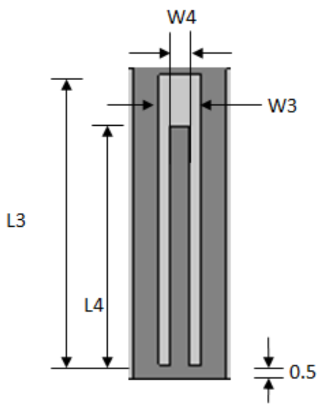

Figure 6.2. 2 Dimensions of inverted U-slot

6.2.2) Simulation Results:

The Return loss curve and vswr curve for the proposed antenna is shown below. From simulation results it can be concluded that the antenna has bandwidth for -10 return loss from 2.4 to 11.8 GHz rather than the two rejected band. Which shows the antenna can be used for the UWB application.

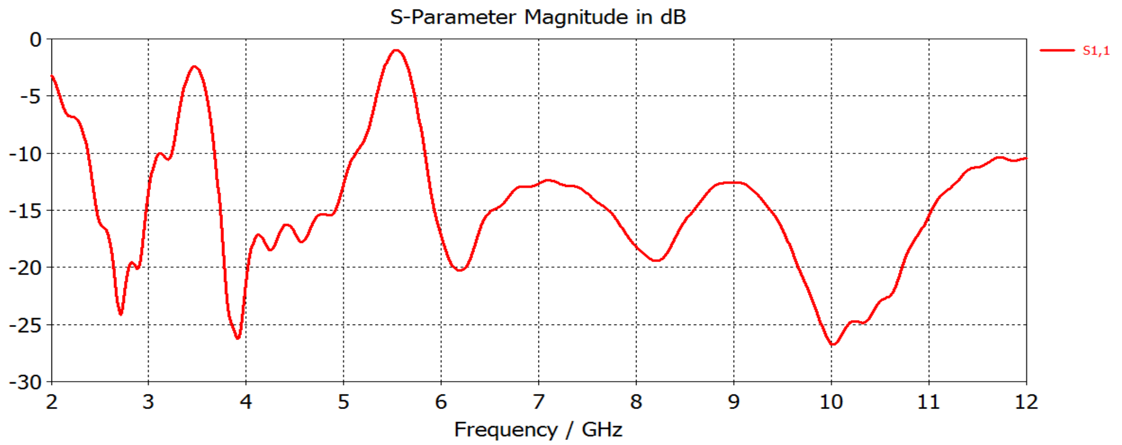

Figure 6.2. 3 Return loss vs frequency curve of proposed antenna.

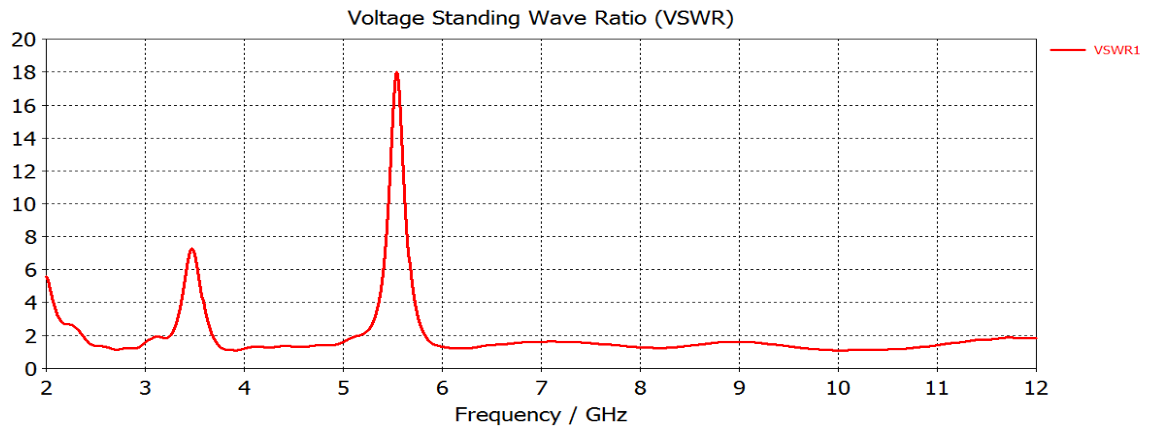

Figure 6.2. 4 VSWR vs frequency curve of proposed antenna.

The effect of the U-slot dimension on vswr curve is observed and shown below. The comparison of different vswr curves for different value of length l1 and width w1 are shown in figure below.

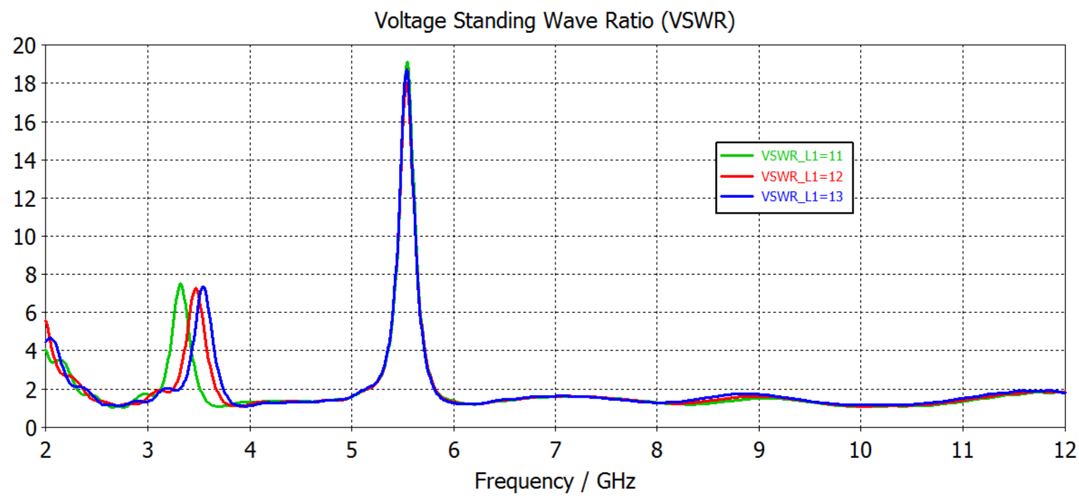

Figure 6.2. 5 VSWR vs frequency curve for different length L1 of U-shape notch.

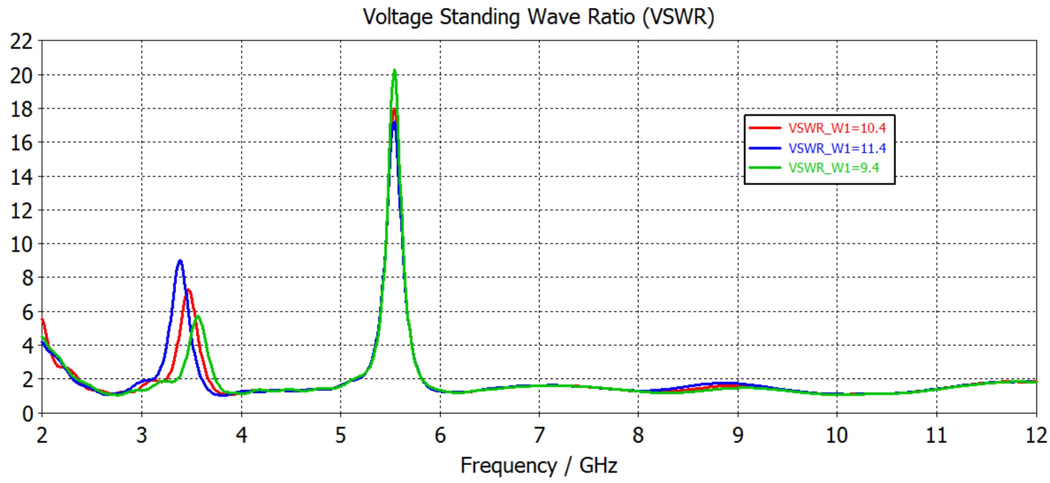

Figure 6.2. 6 VSWR vs frequency curve for different width W1 of U-shape notch.

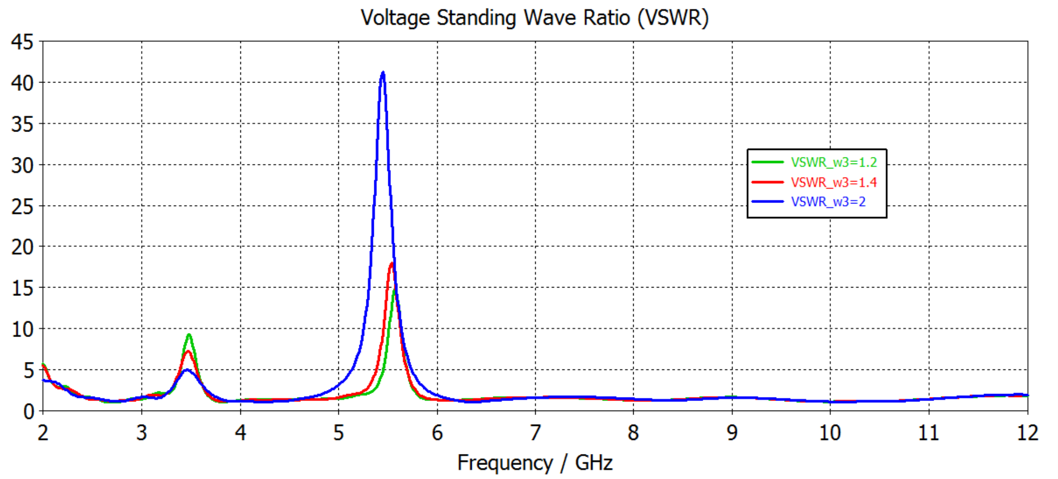

Figure 6.2. 7 VSWR vs frequency curve for different width W3 of U-shape notch.

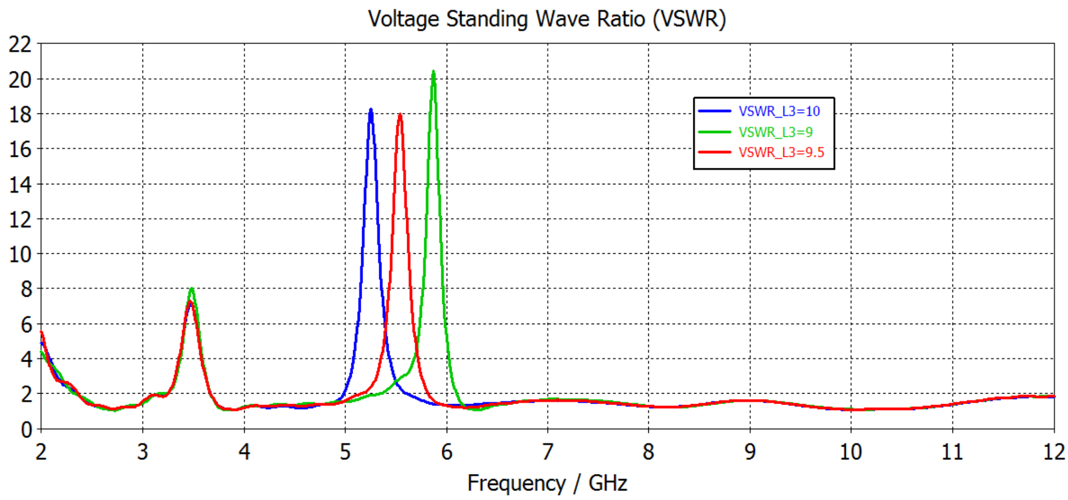

Figure 6.2. 8 VSWR vs frequency curve for different length L3 of U-shape notch.

From the above plots it is seen that the effect of varying the dimension on vswr plot is majorly on the notch frequency to which that dimension belongs to.

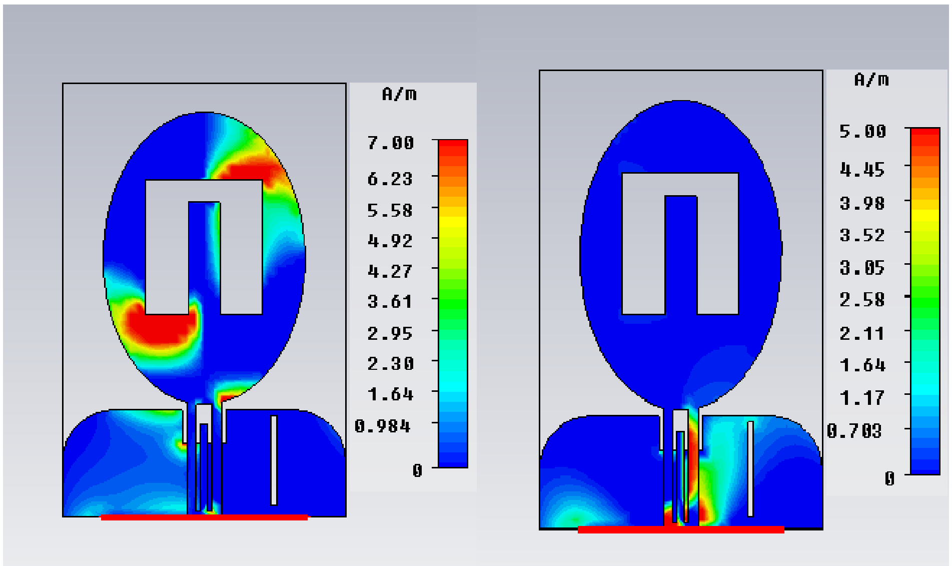

Figure 6.2. 9 Surface current distribution frequency at 3.47GHz and 5.54GHz

As we know that making defects and notches in the patch results in disturbance for current. As we can observe from the above plots the current at 3.47 GHz is mainly focussed on the U-slot on the patch and at 5.54 GHz it is focussed on the slots made on the microstrip feedline. Radiation pattern for these two notch frequencies are shown in figure below.

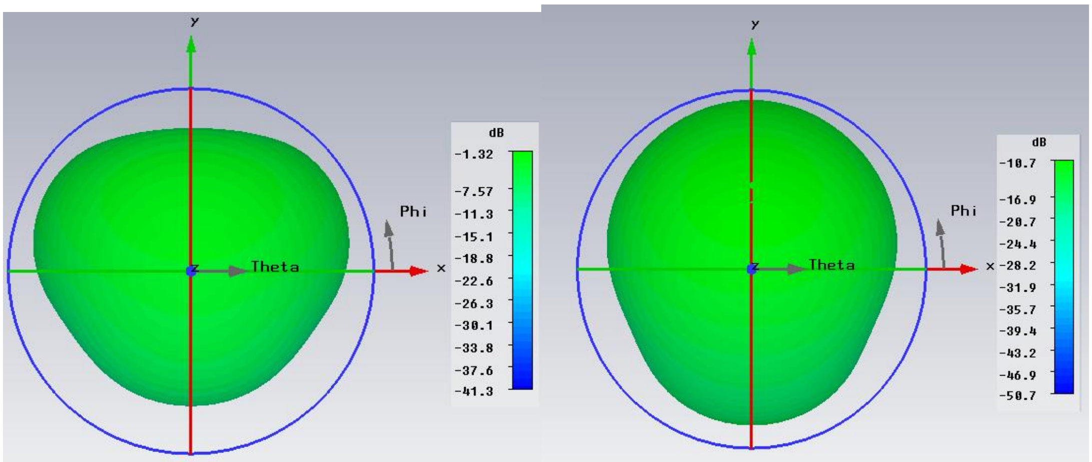

Figure 6.2. 10 Radiation Pattern at frequency 3.47GHz and 5.54GHz

The realized gain vs frequency plot is shown in figure below plot shows that the antenna has minimum gain at the notch frequency - 3.5dB at 3.6GHz and -12dB at 5.6 GHz.

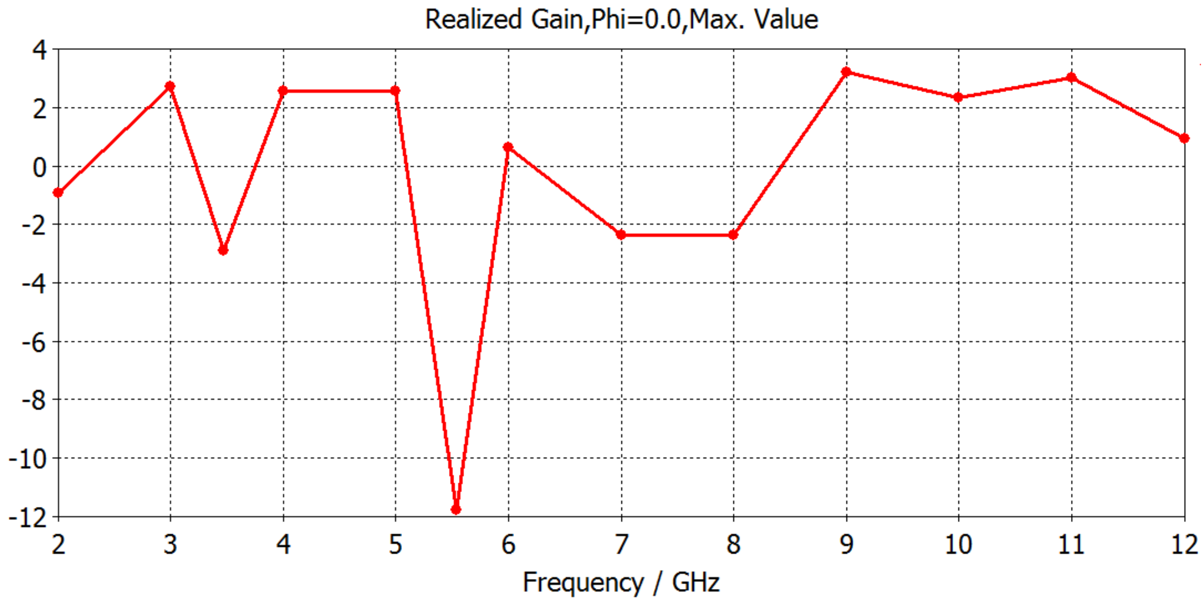

Figure 6.2. 11 Realized Gain vs Frequency plot

6.3)<u>Design 7</u>

<u>Design of UWB Antenna with a Band-Notch for WIMAX</u>

This deign consists of a candy bar shape patch with modified ground plane. Simulation results shows that the proposed antenna covers entire ultra-wide band frequency range except the band notch for the WIMAX application operating in frequency 3.3 GHz to 3.7 GHz. The structural view of the antennas front and back view are shown below.

6.3.1) Antenna design and parameters:

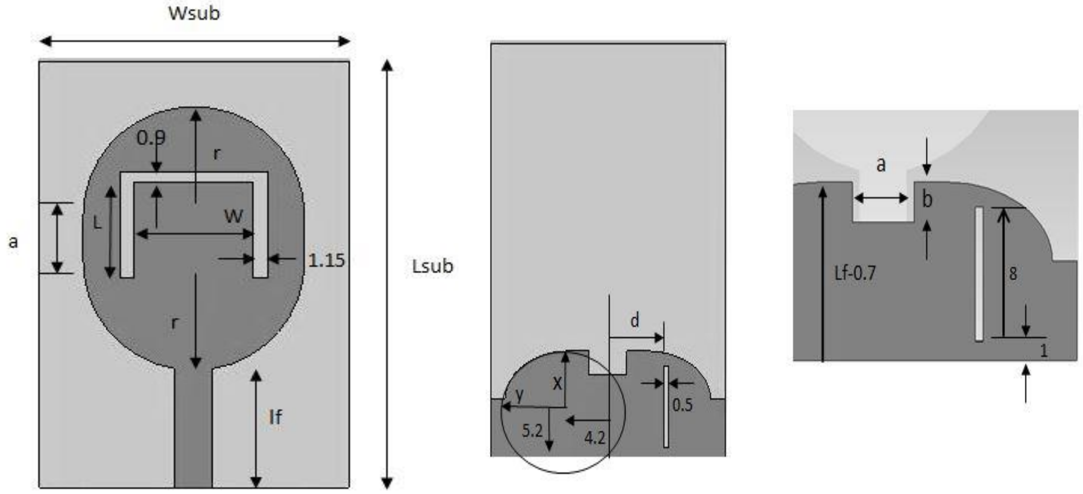

Figure 6.3. 1 Front view and back view with parameters

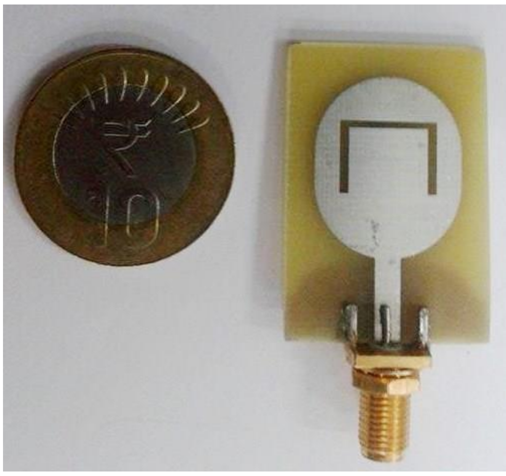

Figure 6.3. 2 Fabricated antenna

The antenna dimensions are listed in the table below.

Table 6. 3 Dimensions of the Proposed 7th Design

Parameter	Description	Value
r	Radius of circle	9
a	Circle overlapping length	4
l	Length of U- slot	8
w	Width of U-slot	8.5
lf	Length of	10
Wf	Width of	3.058
Lsub	Length of	35.6
Wsub	Width of	25.2

As shown in figure Partial ground plane is used in the design and a narrow rectangular slit and a rectangular notch is made in the ground plane to increase the bandwidth .In order to achieve the band rejection characteristic for WIMAX band an inverted U-slot is made in patch. The vswr curve of the designed antenna with optimized parameters is shown below.

6.3.2) Simulation Results:

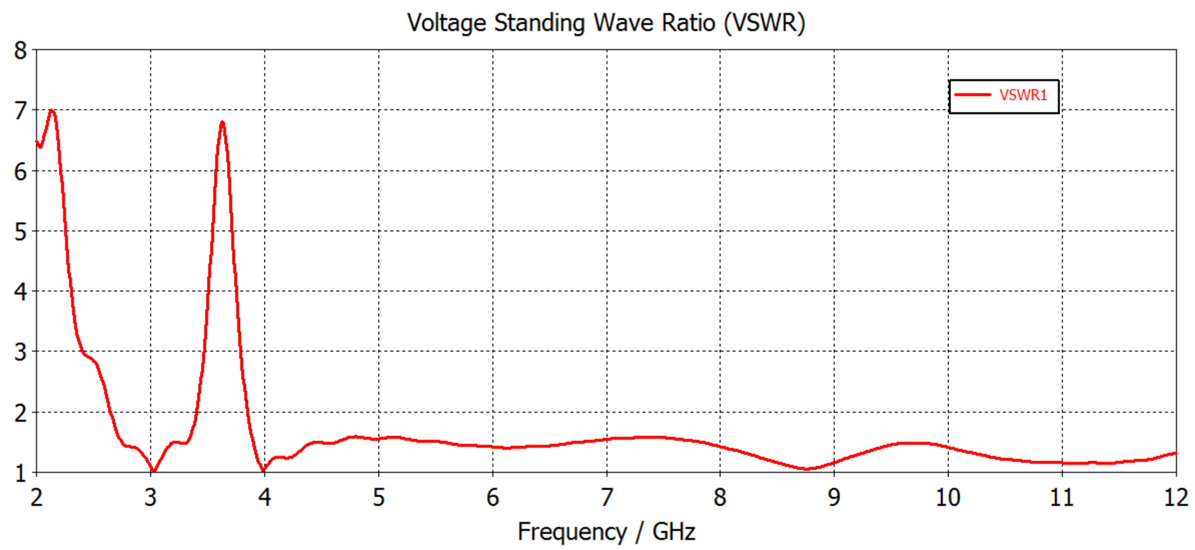

Figure 6.3. 3 VSWR vs frequency curve of designed antenna.

The variation in vswr curve due to change in the slot dimensions length L1 and width W1 is observed and shown in the below graph.

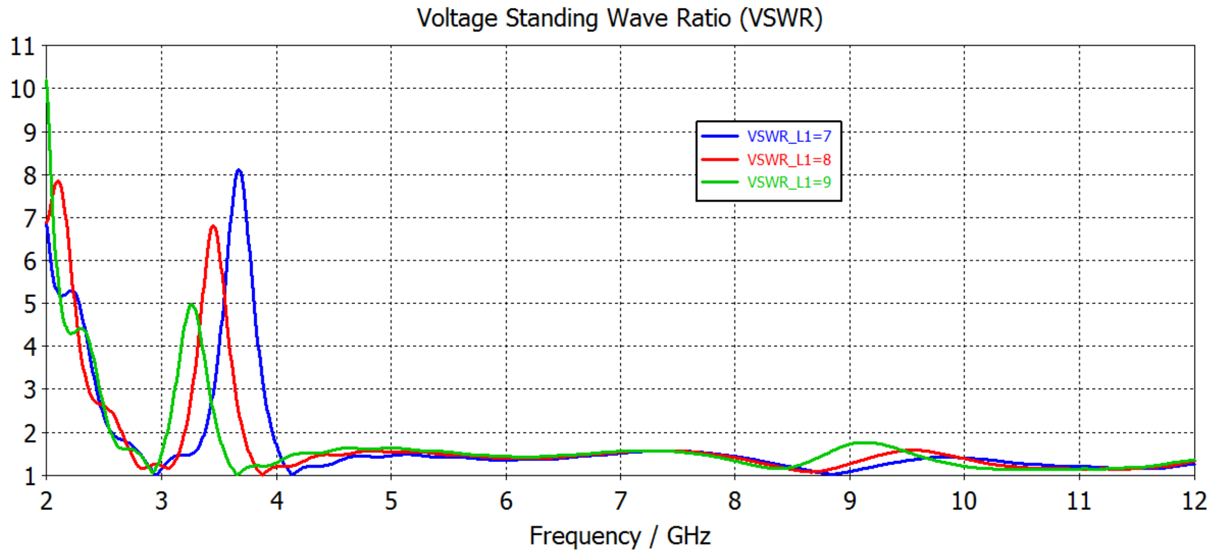

Figure 6.3. 4 VSWR vs frequency curve for different length L1 of U-shape notch.

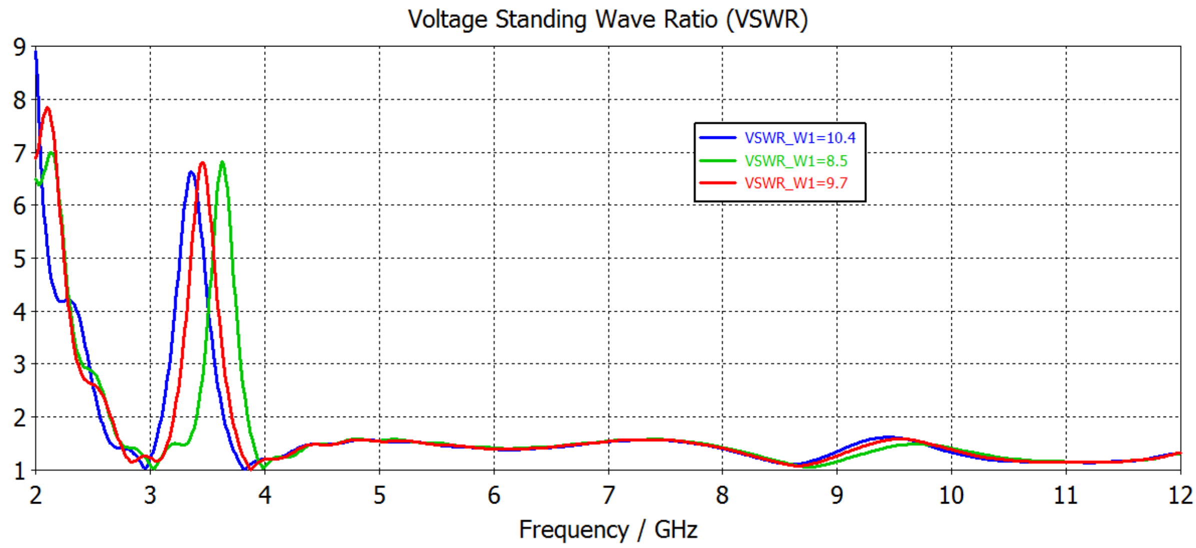

Figure 6.3. 5 VSWR vs frequency curve for different width w1 of U-shape notch.

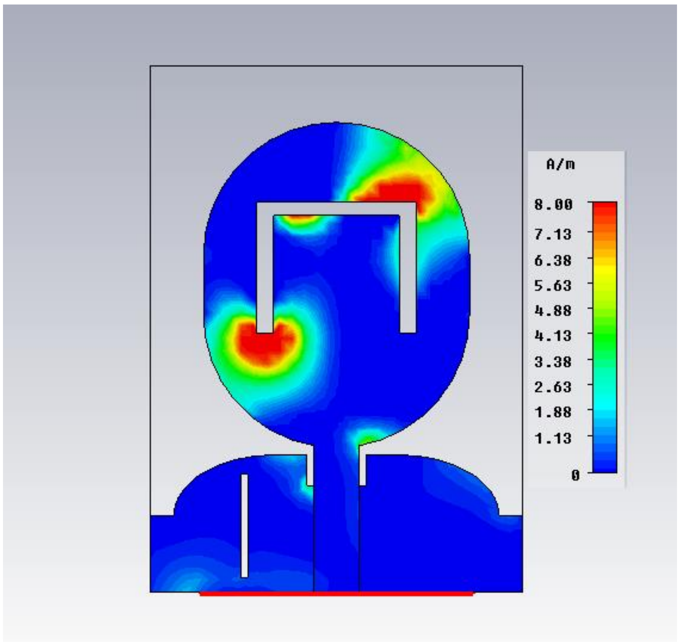

Figure 6.3. 6 Surface current distribution at 3.622 GHz

The above figure shows Surface current distribution on the proposed antenna. It is observed that the current is mainly concentrated along the U shape slot which is responsible for the band rejection at this frequency. The radiation pattern of designed antenna at the notch frequency is shown below.

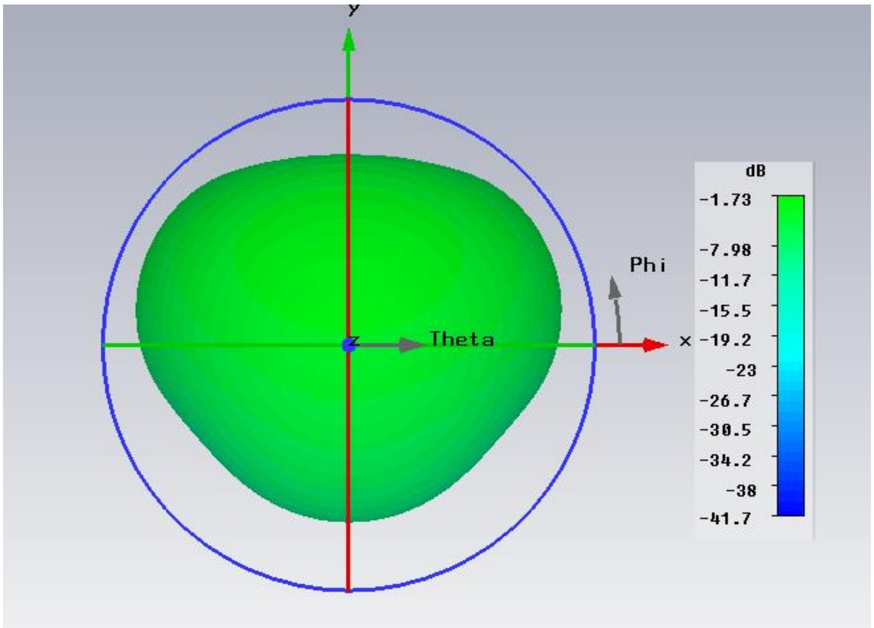

Figure 6.3. 7 Radiation Pattern at 3.622 GHz

The realized gain vs frequency plot is shown in figure below plot shows that the antenna has minimum gain at the notch frequency.

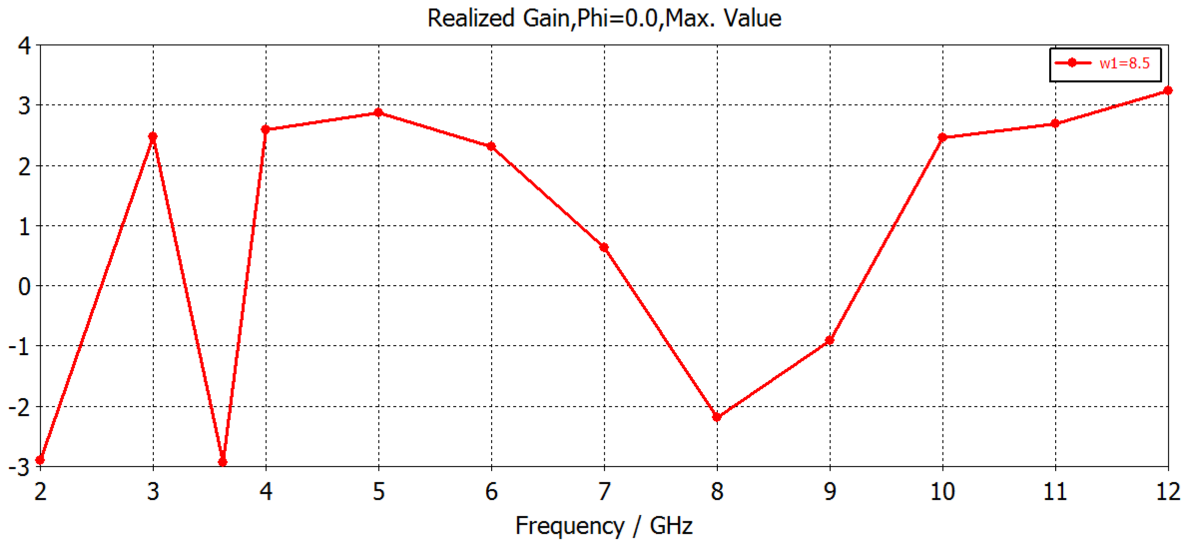

Figure 6.3. 8 Realized Gain vs Frequency plot

Chapter 7

Conclusion and Future Work

7.1) Conclusion and Future Work:

This thesis describes seven different microstrip patch antenna designs with different shapes. Four of them are designed for use in UWB application without any band notches and three of them are designed to work in UWB with different band notches for different applications like (WiMAX) operating in 3.3-3.7 GHz, (WLAN) for IEEE 802.11a 5.15-5.825 GHz, Downlink X-band satellite communication systems in 7.25 - 7.75 GHz.4.5-4.8 GHz INSAT / Super-Extended C-Band (Indian National Satellite systems). The easiest and most common method to achieve a band notch is making a narrow slot of different shapes into the radiating patch of the antenna, will affect the current flow in the patch, different type of shapes is used to make the slots are used to get the band-notched in the desired frequency band. These proposed antenna structure's simulation is carried out using the CAD software Microwave Studio in Computer Simulation Technology Simulator (CST), one commercial 3-D full-wave electromagnetic simulation software. The Simulated results are presented, shows the usefulness of the proposed antenna structure for UWB applications. The simulation results of band notch antenna indicate that the proposed antenna fulfils the excellent triple band notch characteristics for various frequency bands and showing the good return loss and radiation patters in the interested UWB.

New techniques should be explored to reduce the size of the UWB antennas to suit more practical applications. Metamaterial is a promising candidate since it can reduce the size greatly. Some optimization techniques should be used to optimize the optimum results like PSO, Genetic algorithm.

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